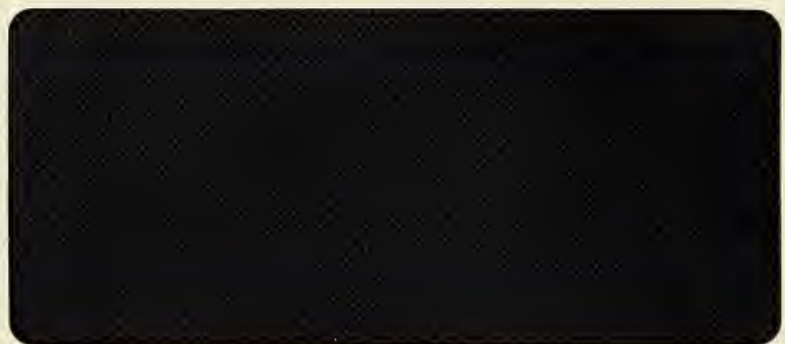


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FINAL REPORT

DELINEATION AND CHARACTERIZATION
OF THE RECHARGE AREA
FOR MITCH HILL SPRING
BUFFALO NATIONAL RIVER, ARKANSAS



OZARK UNDERGROUND LABORATORY

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FINAL REPORT

DELINEATION AND CHARACTERIZATION OF THE RECHARGE AREA FOR MITCH HILL SPRING BUFFALO NATIONAL RIVER, ARKANSAS

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Ozark Underground Laboratory

February, 1989

An investigation conducted for the Buffalo National River, National
Park Service, under purchase order PX7150-7-0314.

ABSTRACT

Mitch Hill Spring is a large spring tributary to the Buffalo National River in Newton County, Arkansas. This report documents groundwater tracing studies conducted to delineate the area contributing water to this spring. Tracing dyes were injected into the groundwater through six different sinkholes and losing stream segments. The dyes were subsequently recovered from 15 different sampling stations; there were 26 positive groundwater traces resulting from the six dye injections. Five of the six dye injection sites are located within the recharge area for Mitch Hill Spring.

The recharge area for Mitch Hill Spring was subjected to a hazard area mapping. This mapping identifies areas which present different levels of risk to the quality of water in Mitch Hill Spring. A large portion of the Mitch Hill Spring recharge area was identified as presenting "Extremely High Hazards" or "High Hazards" of groundwater contamination.

Five potential groundwater contamination sites were identified based upon existing or proposed land use. The site with the greatest potential for degrading water quality at Mitch Hill Spring was Site 5, the proposed Bob Cash Landfill. Leaks or spills along highways crossing the recharge area also constitute a significant water quality threat to Mitch Hill Spring.

The SPG Well is the sole source of public water for the communities of St. Joe, Pindall, and Gilbert. It lies within the Mitch Hill Spring recharge area. Three of our six groundwater traces yielded dye recoveries at the SPG Well; based upon this data, the recharge area for this well consists of approximately 13.4 square miles. The recharge area for the SPG Well includes the proposed Bob Cash Landfill.

EXECUTIVE SUMMARY

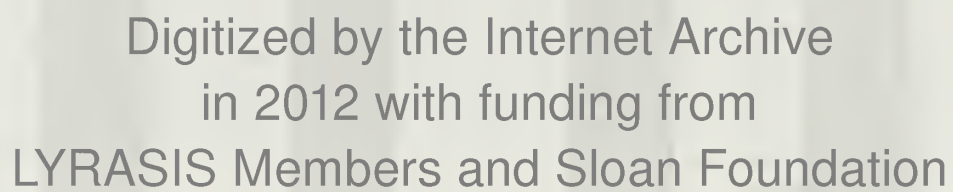
Mitch Hill Spring is a major tributary to the Buffalo National River near Mt. Hersey. A recharge area for a spring is the area which contributes at least some waters to that spring. This investigation delineated the recharge area for Mitch Hill Spring; the delineated area comprises 20.8 square miles and is located generally northeast of the spring. The recharge area for Mitch Hill Spring includes portions of five topographic stream basins; these are Clear Creek, Mill Creek, Mill Branch, and Cane Branch.

The recharge area for Mitch Hill Spring is a karst area developed upon extensive limestone and dolomitic rock units. Much of the annual runoff water from the area enters the groundwater system and subsequently discharges from the springs of the area.

The delineation of the Mitch Hill Spring recharge area was conducted using fluorescein and Rhodamine WT groundwater tracing dyes. Sites where tracer dyes were injected into the groundwater system consisted of sinkholes or losing streams. A total of six injection sites were used. A total of 29 sampling stations were used for detecting the tracer dyes; some of these stations were not used in all of the traces. Tracer dyes were recovered from 15 different sampling stations; there were a total of 26 successful traces. There were five successful traces to Mitch Hill Spring; this spring was the primary focus of our groundwater tracing studies.

Our groundwater tracing showed several important characteristics of the groundwater system which contributes waters to Mitch Hill Spring. These characteristics included the following:

- 1) Directions of some groundwater flow in the study area change with changes in hydrologic conditions.
- 2) Much of the recharge area for Mitch Hill Spring also contributes waters to other springs.
- 3) Approximately 13.4 square miles of the recharge area for Mitch Hill Spring also provides water for the SPG well, a rural water district well near Pindall. This well is the sole public water supply for the communities of St. Joe, Pindall, and Gilbert.
- 4) Within the delineated recharge area the Mill Creek Graben, which is bounded by the Mill Creek and St. Joe Faults, is an extremely important groundwater recharge area.
- 5) Within the delineated recharge area Clear Creek and its tributaries



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are extremely important groundwater recharge areas.

6) Faults, lineaments, and fracture traces are important routes for groundwater flow in the study area.

Reconnaissance-scale optical brightener sampling was conducted in the study area. Optical brighteners are fluorescent dyes present in most laundry soaps and detergents; they are an indicator of sewage contamination of groundwater. Optical brighteners were detected at several groundwater sampling stations in the study area. Optical brightener samplers at Mitch Hill Spring were weakly positive for optical brighteners.

Hazard area mapping of the study area was conducted. This mapping identifies areas which present different levels of risk to the quality of water in Mitch Hill Spring. A large portion of the Mitch Hill Spring recharge area was identified as presenting "Extremely High Hazards" or "High Hazards" of groundwater contamination.

Five potential groundwater contamination sites were identified based upon existing or proposed land use. Each was discussed and evaluated. The site with the greatest potential for degrading water quality at Mitch Hill Spring was Site 5, the proposed Bob Cash Landfill. Leaks or spills along highways crossing the recharge area also constitute a water quality threat to Mitch Hill Spring.

Six management recommendations for protecting the water quality of Mitch Hill Spring are made in a final section of the report (see page 66). These recommendations will not be repeated here.

Large amounts of appendix data were developed and are presented in a separate volume to this report. These data present useful and permanent documentation of the analysis work conducted, but will not be needed by most users of this report.

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Map Sheet 2. Groundwater Tracing Results in the Study Area.
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APPENDIXES (Bound in Volume 2)

- Appendix A.** Tabulated Results from all Dye Sampling Stations.
Appendix B. Dye Sampling Analysis Methods.
Appendix C. All RF-540 Analysis Charts for Dye Tracing Samplers.
Appendix D. All RF-540 Analysis Charts for Optical Brightener Samplers.

INTRODUCTION

Mitch Hill Spring is a crucially important feature on the Buffalo National River near Mt. Hersey. This investigation was designed to provide fundamental information on the recharge area for this spring. A recharge area for a spring is the area which contributes water to the spring. Additionally, the study was designed to assess activities which might affect the water quality of this spring.

Field work began in October, 1987. Previous hydrogeologic work in the Mitch Hill Spring recharge area was conducted during the period 1985 through 1987. This prior work was conducted for CALF, a citizen's group concerned with protecting groundwater quality in the region from a proposed landfill planned for a site about a mile southwest of Pindall. Some of the work conducted for CALF is incorporated in this report; we thank CALF for allowing us to use this information. We also thank residents of the area for their cooperation and help in the present investigation.

Location of the Study Area

The general location of the study area is shown on maps which accompany this report. The area is roughly bounded by the Buffalo River on the south, a north-south line drawn through St. Joe on the east, the line between Searcy County and Boone and Marion Counties on the north, and a north-south line a mile and a half west of the Searcy and Newton County line on the west. Most of the study area is in Searcy County, but portions of other counties are included.

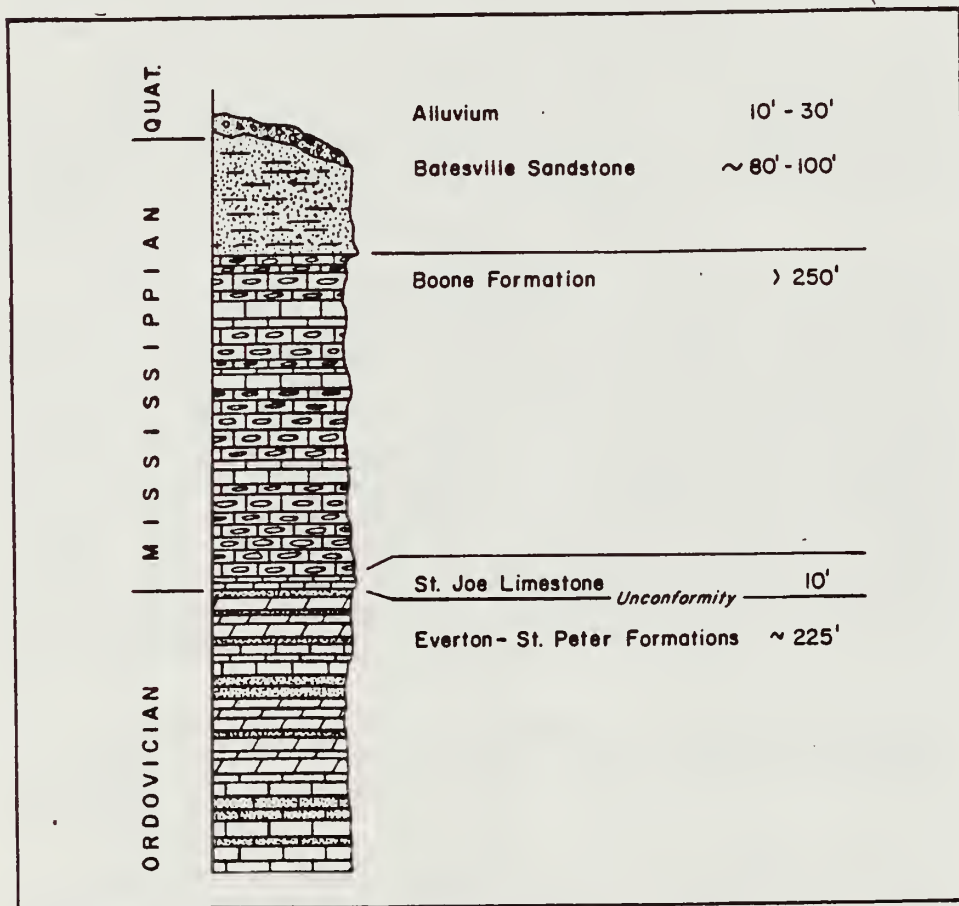
The community of Western Grove lies outside of the study area even though it lies within the area roughly described above. The town of St. Joe also lies outside of the study area. Pindall is the only community located within the study area.

Geology of the Study Area

Map Sheet 1 (in the folder in the back of this report) depicts the geology of the area studied. Five major geologic mapping units are recognized in the area. There is a sixth unit, mapped as undifferentiated Middle and Upper Ordovician units, which is of minor extent and is found only in parts of the study area.

Figure 1 depicts the typical stratigraphic section of the Mitch Hill Spring recharge area; the undifferentiated Middle and Upper Ordovician units are excluded. Figure 1 is from Thomson (1985); the various geologic units are described by Thomson (1985) as follows.

Figure 1. Stratigraphic section of the Pindall area (Thomson, 1985).



"Alluvium (Quaternary): Fairly substantial thicknesses of alluvial materials have accumulated in the valleys near Pindall. At least 10 to 30 feet or more can be expected. In the valley to the south of Pindall, there is from 5 to 15 feet of alluvial material mainly composed of angular to subrounded chert fragments ranging in size from pebbles to cobbles. Quartz sand can also be found in the fine constituents.

"Batesville Formation (Mississippian): In the area of study the Batesville Formation can be seen outcropping near Chinquapin Spring. Here it consists of a medium grained, reddish-brown micaceous slabby sandstone. It occurs in beds which range from 4 inches to 2-3 feet thick. In this area about 80 to 100 feet of Batesville remain.

"Boone Formation (Mississippian): The Boone Formation is composed of gray micritic limestone and white to gray chert. In some occurrences the chert may comprise as much as 60 to 70 percent of the rock. In these areas, the rock weathers easily and outcrops are scarce. In areas in which less chert occurs, outcrops can be seen. Some of these are found along the road south of Pindall where it crosses Mill Creek. Outcrops can also be observed along the old railroad grade in Mill Creek valley. In these areas the formation is medium to thick bedded. The thickness cannot be measured in this area because the top and bottom could not be accurately located. However, it is estimated that the thickness in the Pindall area is over 250 feet.

"The St. Joe Member of the Boone was observed just north of Pindall where about 10 feet of red, finely crystalline-crinoidal limestone could be seen. This was not observed in any other area.

"Everton-St. Peter Formations Undifferentiated (Ordovician): The uppermost portion of this unit consists of a quartz sandstone which is pale brown to whitish grading to a deeper reddish brown. The sand grains are fine to medium grained, fairly well rounded and cemented with carbonate and iron cement. In many places it is a bluff or ledge former and outcrops can be observed northwest of Pindall and along the road south of Pindall, both north and south of Mill Creek. To the north of Mill Creek, the outcrop is evident on the east side of the road, and can also be seen on the hills west of

the road. In this outcrop the beds were thin to medium bedded and were dipping to the north at from 7 to 10 degrees. South of Mill Creek the beds were dipping slightly to the south and could be observed on the west side of the road. A dolomite unit can be found below the sandstone and according to McKnight (1935), the Everton contains interbedded dolomites and sandstones for most of its thickness. The dolomite is a fine-grained, light gray to white mottled rock. According to Caplan (1975), the Everton-St. Peter Formation is about 225 feet thick in northwest Searcy County."

Thomson (1985) did not describe the **Undifferentiated Middle and Upper Ordovician** units. This mapping unit consists (from bottom to top) of the Platin Limestone, Fernvale Limestone, and the Cason Shale. It should be noted that areas mapped as undifferentiated Middle and Upper Ordovician units do not necessarily include all three of the named geologic units. It is common for one or more of the units to be absent or represented by only a very minor bed of rock. In particular, the Cason Shale is often absent or extremely thin. The Platin Limestone is an evenly bedded, dark gray, finely crystalline to sublithographic limestone which contains minor amount of intercalated shale. The basal unit is easily recognized because it is composed of a pebble conglomerate and oolite, and contains shale. The Fernvale Limestone is a generally thin geologic unit consisting of light gray, coarsely crystalline, highly fossiliferous limestone which is evenly bedded in layers not exceeding a few inches in thickness.

Thomson (1985) also provided an excellent discussion of geologic structure in the area. Excerpted portions of his description (Thomson, 1985) follow.

"The general appearance of the structure in this part of Arkansas is that of horizontal beds. However, there are some gentle regional dips of less than 1 degree here. In the Pindall area, the general dip is to the north at about 100 feet per mile. South of Mill Creek the dip is about the same, but to the south. There are some areas of greater localized dip. In the roadcuts south of Pindall in the Everton-St. Peter Formations, dips ranging from 7 to 10 degrees were measured. To the west of the same road the sandstone forms a dip slope on some of the hills, again dipping to the north in excess of 5 degrees.

"These gently dipping rocks which seem to be uplifted in the southern part of the area have been cut east-west by two major normal faults, the St. Joe and the Mill Creek. These faults form the boundaries for the east-west trending Mill Creek Graben.

"The St. Joe Fault is an east-west trending fault that extends all the way across the south part of the study area. Its displacement is up to 500 feet and total east-west extent is 15 miles (McKnight, 1935). Evidence for this fault is abundant in the study area. The following are sites seen by this investigator [Thomson].

"1. On the east side of the area, several hills show an excellent photolineament. Here the fault shows up with several low hills separated from their ridges by the fault. These can be aligned with the fault quite easily. The way the hills themselves have been displaced, indicates that the south side of the fault was the downthrown side. These hills can be seen on the topographic map on the south side of section 11, T16S, R18W.

"2. Along the road extending south from Pindall, we can see the sandstone of the Everton-St. Peter in fault contact with the Boone Formation. Exposures are excellent on the east side of the road.

"3. At this same location, abundant chert breccia can be observed. This contains angular chert fragments which have been caught up in a dark colored matrix of ground up material. In several of the pieces of the breccia are quartz crystals lined geodes or vugs.

"4. To the west of this location in the southwest quarter of section 10, three prospect pits are along the fault. This appearance is justified by the fact that there is Ordovician sandstone on the north side of the pits and Boone limestone on the south side.

"5. To the northwest of Chinquapin Spring, the fault contact between the Batesville Sandstone and the Boone Formation can be seen in the road as you drive out of the sandstone and into the limestone proceeding northwest. This can be seen in the east half of section 8, T16N, R18W.

The Mill Creek Fault parallels the St. Joe about 1500 to 2000 feet south of it. Its offset is approximately 150 feet and it also extends for 15 miles (McKnight, 1935). There are several places where the evidence for the fault can be seen:

"1. A strong photolineament follows Mill Creek which aligns with the fault.

"2. The Everton-St. Peter Formation sandstone outcrops just south of Mill Creek along the road from Pindall. Here, in the north-center of section 15, it occurs at an elevation of 1100 feet. On the north side of the creek, there is only Boone Formation down to about 1060 feet.

3. The Batesville Sandstone is in fault contact with the Boone Formation near Chinquapin Spring. The Boone is on the south and the Batesville Sandstone is on the north and lower than the stratigraphically lower Boone Formation. This fault contact can be followed for at least 1 1/2 miles to the west past the head of Cane Branch.

GROUNDWATER TRACING INVESTIGATIONS

Methods

Two fluorescent dyes have been used in our current groundwater tracing studies. They are fluorescein and Rhodamine WT. The groundwater tracing investigations involve the introduction of small amounts of dye into the groundwater system; springs, streams, and wells are sampled to determine where the waters return to the surface.

All sampling for tracer dyes uses packets of activated charcoal which are placed in the springs or streams to be sampled. When wells are sampled, a flow rate of about one gallon per minute is continuously passed through a charcoal packet which is placed in holder which is attached to faucet or garden hose. The holder is constructed of plastic pipe and is designed to pass all water through the charcoal packet while keeping the packet in the dark. If either of the tracer dyes is present in the water being sampled, some of the dye will be adsorbed on the charcoal.

The charcoal packets are periodically recovered and new packets are placed. The used packets are washed, then treated with an alcohol, water, and base eluting solution. This causes some of the adsorbed dye to detach from the charcoal and move into the eluting solution. The eluting solution is then subjected to analysis in a Shimadzu RF-540 Spectrofluorophotometer. Using our analysis protocol, if fluorescein dye is present it will produce a fluorescence peak at about 519 nm. If Rhodamine WT dye is present, it will produce a fluorescence peak at about 572 nm. Dye concentrations can be calculated by comparing the magnitude of fluorescence peaks with standards which are routinely run.

A detailed description of the methodology utilized in our groundwater tracing work is explained in the two documents found in Appendix B. These documents are:

- 1) "Procedure for analysis of fluorescein and Rhodamine WT dyes in charcoal samplers."
- 2) "Interpretation of the RF-540 Charts".

Appendix C includes all RF-540 analysis graphs for all sampling stations used in the groundwater tracing program. It does not include RF-540 analysis charts for optical brightener detection.

Sampling Stations

The purpose of this study was to delineate the recharge area for Mitch Hill Spring. This station is obviously one of the most important sampling stations, yet thorough groundwater tracing programs need to monitor numerous springs in the area. We also monitored some wells during our tracing work.

Table 1 lists sampling stations used by the Ozark Underground Laboratory in conjunction with dye tracing investigations in the study area during the 1987-88 tracing program. Stations 26 through 29 were positive dye recovery stations which were used in conjunction with our 1986 groundwater tracing in the area; they were not used during our 1987-88 tracing program.

Dye Injection Sites

Five separate groundwater traces were conducted during our 1987-88 groundwater tracing program. Prior to this contract we conducted a groundwater trace in the area during 1986; we have incorporated those data into this report with the kind permission of CALF of Pindall, Arkansas.

Each dye trace is identified with an identification number. The first two digits indicate the year in which the trace was begun. The second two digits indicate the order in which the trace was conducted during the particular year. As an illustration, Trace 87-01 was the first trace conducted in the study area during 1987. Tables 2 through 7 summarize basic data on each of the six dye injection sites used in the study area.

Table 1. Sampling Stations

Station Number and Name	Location	Elevation (feet)
1. Blaine Young Well.	In Pindall. NE SE Sec 10, T16N, R18W.	Water level abt. 1,025
2. Ralph Wallace Well	In Pindall. SW NE Sec 3, T16N, R18W	Water level abt. 1,025
3. SPG Well	SE SW Sec 2, T16N, R18W	865 on 1/82
4. Wiley Moore Spr.	SW SW Sec 2, T16N, R18W	1,100
5. Bull Hollow Spr.	NE SW Sec 26, T16N, R18W	780
6. Three Forks Sprs.	SW SE Sec 8, T16N, R18W	1,000
7. Cave Spr.	NE NE Sec 21, T16N, R18W	980
8. Odie Moore Spr.	NE SE Sec 32, T17N, R18W	1,080
9. Murray Spr.	NW SE Sec 29, T17N, R18W	1,020
10. Dugger (Rockhole) Spr.	NW NW Sec 21, T17N, R18W	920
11. Glenco Spr.	SW SW Sec 22, T17N, R18W	980
12. Cannon Spr.	SW NW Sec 13, T16N, R18W	940
13. Mill Cr. (St. Joe) Spr.	NW SW Sec 17, T16N, R17W	800
14. Mill Cr. Mine Spr.	NE NE Sec. 18, T16N, R17W.	800
15. Johnson Spr.	NW NE Sec 26, T16N, R19W	695
16. Mitch Hill Spr.	NE NW Sec 25, T16N, R19W	720
17. Deaton Spr. #1	SE NW Sec 12, T16N, R19W	950
18. Jamison Spr.	NW SE Sec 26, T16N, R18W	720
19. Jack Keith Spr.	NW SW Sec 34, T17N, R18W	1,020
20. Chinquapin Spr.	SE SE Sec 8, T16N, R18W	1,020
21. Henthorne Spr.	NW NW Sec 4, T16N, R18W	1,090

Table 1 (continued). Sampling Stations

Station Number and Name	Location	Elevation (feet)
22. Deaton Spr. #2	NE NW Sec 12, T16N, R19W	1,140
23. Cane Br. at mouth	SE SE Sec 31, T16N, R18W	735
24. Lewis Well	NE SE Sec 33, T17N, R18W	water level abt. 990
25. Hurricane Spr.	NE NW Sec 7, T16N, R18W	1,080
26. Paul Holder Well	NE SW Sec 10, T16N, R18W.	1,099 ft. on 7/19/85.
27. Virgel Henson Well	In Pindall. SE NW Sec 3, T16N, R18W.	Water level abt. 1,025
28. Ernest Herron Well	In Pindall. NE NW Sec 3, T16N, R18W.	Water level abt. 1,025
29. Rachel Nichols Well	In Pindall. SE NW Sec 3, T16N, R18W.	Water level abt. 1,025

Table 2. Dye Injection Site Data for Trace 86-01.

Injection Location: Holder Sinkhole. A shallow sinkhole about 12 feet in diameter and about 2 feet deep in the floor of an unnamed tributary to Clear Creek. The sinkhole is 130 feet from the formerly-proposed Pindall Landfill. SE NW Sec. 10, T16N, R18W. Surface elevation approximately 1,175 feet.

Geologic Setting: Within the Boone Formation.

Date and Time of Dye Injection: January 13, 1986 between 11:55 AM and Noon.

Tracing Agent and Amount: 9 pounds of fluorescein (pre-dissolved in water).

Wells Nearby?: Nearest drinking water well is Paul Holder Well 1,500 feet to the south.

Dye Recovery Locations: See following list. Additional data in Aley (1986 and 1986A).

Trace 86-01. Holder Sinkhole

Dye Recovery Site	Distance and Direction from Injection Site	Time of First Dye Arrival (Days After Injection)
Holder Well	1,500 ft. south	within 5 days
Cannon Spring	11,400 ft. southeast	3 to 5 days
Keith Spring	8,400 ft. north	26 to 33 days
Young Well	5,250 ft. north	38 to 41 days
Henson Well	5,200 ft. north	38 to 41 days
Herron Well	5,300 ft. north	38 to 41 days
Nichols Well	4,800 ft. north	38 to 41 days
Mitch Hill Spring	23,500 ft. southwest	about 61 days

Table 3. Dye Injection Site Data for Trace 87-01.

Injection Location: Losing stream segment of Clear Creek downstream of Wiley Moore Spring. SW SW Sec. 2, T16N, R18W. Elevation approximately 1,095 feet.

Geologic Setting: Within the Boone Formation.

Date of Dye Injection: November 16, 1987. Prior to the injection about 4.5 inches of rain fell in the area on November 15 and the early morning hours of November 16.

Tracing Agent and Amount: Three pounds of fluorescein dye (powder form).

Wells Nearby?: No. Nearest well about 1,600 feet.

Dye Recovery Locations: See following list.

Trace 87-01. Clear Creek downstream of Wiley Moore Spring

Dye Recovery Site	Distance and Direction from Injection Site	Time of First Dye Arrival (Days After Injection)
Wallace Well	4,000 ft. northwest	within 7 days
Keith Spring	8,100 ft. northwest	within 7 days
Dugger Spring	21,800 ft. northwest	within 7 days
SPG Well	1,600 ft. southeast	within 7 days
Mill Creek Mine Spring	16,300 ft. southeast	7 to 14 days
Mitch Hill Spring	28,700 ft. southwest	14 to 21 days
Upper Hurricane Creek Springs	18,600 ft. west	14 to 28 days
Deaton Spring #1	22,700 ft. west	21 to 28 days

Table 4. Dye Injection Site Data for Trace 87-02.

Injection Location: Sinkhole near the Kilburn Cemetery. The injection site is located in the SW SW Section 9, T16N, R18W at an elevation of about 1,240 feet.

Geologic Setting: Batesville Formation. Essentially on the Mill Creek Fault.

Date of Dye Injection: November 16, 1987. Prior to the injection about 4.5 inches of rain fell in the area on November 15 and the early morning hours of November 16.

Tracing Agent and Amount: 4 pounds of 20% Rhodamine WT dye (liquid form).

Wells Nearby?: No.

Dye Recovery Locations: See following list.

Trace 87-02. Kilburn Cemetery

Dye Recovery Site	Distance and Direction from Injection Site	Time of First Dye Arrival (Days After Injection)
Wallace Well	9,900 ft. northeast	within 7 days
SPG Well	12,200 ft. northeast	within 7 days
Deaton Spring #1	12,700 ft. west	within 7 days
Cannon Spring	15,700 feet east	7 to 14 days
Mitch Hill Spring	17,800 ft. southwest	7 to 14 days

Table 5. Dye Injection Site Data for Trace 88-01

Injection Location: Hurricane Mine Trace; in bottom of collapsed mine pit. SW NE Section 7, T16N, R18W. Elevation 1,060 feet.

Geologic Setting: On the St. Joe Fault. Most of the water appears to move into the Boone Formation side of the fault.

Date and Time of Dye Injection: January 21, 1988. Day 110 of the 1987-88 study.

Tracing Agent and Amount: 3 pounds of fluorescein dye (powder form).

Wells Nearby?: No.

Dye Recovery Locations: See following list.

Trace 88-01. Hurricane Mine.

Dye Recovery Site	Distance and Direction from Injection Site	Time of First Dye Arrival (Days After Injection)
Deaton Spring #1	4,800 ft. west	within 36 days
Mitch Hill Spring	15,100 ft. southwest	36 to 65 days

Table 6. Dye Injection Site Data for Trace 88-02.

Injection Location: Cave Spring Branch 1/4 mile downstream of Cave Spring. NW NE Sec 21, T16N, R18W. Elevation 925 ft.

Geologic Setting: Everton-St. Peter Formations.

Date and Time of Dye Injection: June 3, 1988 at 1:00 pm

Tracing Agent and Amount: 2 lbs Rhodamine WT solution (20% solution).

Wells Nearby?: None.

Dye Recovery Locations: See following list.

Trace 88-02. Cave Spring Branch

Dye Recovery Site	Distance and Direction from Injection Site	Time of First Dye Arrival (Days After Injection)
Mouth of Cane Branch	17,000 ft. southwest	within 13 days

Table 7. Dye Injection Site Data for Trace 88-03.

Injection Location: Losing stream segment of Clear Creek downstream of Jack Keith Spring. The entire flow from Keith Spring sinks in the vicinity of the injection site for a few days prior to the rather abrupt end of discharge from Keith Spring. Injection site is in the NW SW Sec 34, T17N, R18W. Approximate elevation 1,005 feet.

Geologic Setting: Everton-St. Peter Formations.

Date and Time of Dye Injection: 1:00 pm June 7, 1988.

Tracing Agent and Amount: 3 pounds of fluorescein dye.

Wells Nearby?: Lewis Well. Dug well 30 to 40 ft. deep. Well sampled, but no dye recovered.

Dye Recovery Locations: See following list.

Trace 88-03. Clear Creek downstream of Jack Keith Spring.

Dye Recovery Site	Distance and Direction from Injection Site	Time of First Dye Arrival (Days After Injection)
Mitch Hill Spring	29,000 ft. southwest	within 13 days
SPG Well	10,600 ft. southeast	13 to 24 days

Summary of Dye Tracing Results

This section of the report summarizes dye tracing results on a station by station basis. There is a sub-section for each monitoring station where dye from one or more traces was recovered. For the traces conducted during the 1987-88 groundwater tracing program we have graphically depicted dye concentrations in the samplers from each of the stations where dye was recovered. There are separate graphs for fluorescein dye recoveries and for Rhodamine WT recoveries. The time depictions on the graphs are for the mid-point of the sampling period; the samplers are cumulative samplers.

The reader should keep in mind that the dye concentrations are reflective of the amount of dye present in the eluting solution from charcoal packets. The concentrations do not indicate dye concentrations in the waters present at the sampling station. The dye concentration values are useful in understanding travel times through the groundwater system and whether or not the dye discharged from the monitoring station as a relatively short duration pulse or as a longer duration event. As an illustration of the latter, compare tracing results from Station 16 (Mitch Hill Spring) with results from Station 17 (Deaton Spring #1). Mitch Hill Spring typically discharges relatively short duration dye pulses while those from Deaton Spring #1 for traces 87-02 and 88-01 were much longer duration events.

Table 8 summarizes all positive dye traces in the study area. Appendix A provides tabular sampling results for each of the sampling stations used in the 1987-88 groundwater tracing program. Appendix A also includes a summary of sampling results from the 1986 groundwater trace from the Paul Holder Sinkhole; these data start on page A-27.

Table 8. Summary of Positive Dye Traces

Station Number and Name	Trace 86-01	Trace 87-01	Trace 87-02	Trace 88-01	Trace 88-02	Trace 88-03
1. Blaine Young Well	Pos	ND	ND	NS	NS	NS
2. Ralph Wallace Well	NS	Pos	Pos	NS	NS	NS
3. SPG Well	ND	Pos	Pos	ND	ND	Pos
10. Dugger Spr.	ND	Pos	ND	ND	ND	ND
12. Cannon Spr.	Pos	ND	Pos	ND	ND	ND
14. Mill Cr. Mine Spr.	NS	Pos	ND	ND	ND	ND
16. Mitch Hill Spr.	Pos	Pos	Pos	Pos	ND	Pos
17. Deaton Spr. 1	NS	Pos	Pos	Pos	ND	ND
19. Jack Keith Spr.	Pos	Pos	ND	ND	ND	ND
23. Mouth Cane Br.	NS	NS	NS	NS	Pos.	ND
25. Upper Hurricane Cr. Spr.	NS	Pos	NS	NS	NS	NS
26. Paul Holder Well	Pos	NS	NS	NS	NS	NS
27. Virgel Henson Well	Pos	NS	NS	NS	NS	NS
28. Ernest Herron Well	Pos	NS	NS	NS	NS	NS
29. Rachel Nichols Well	Pos	NS	NS	NS	NS	NS

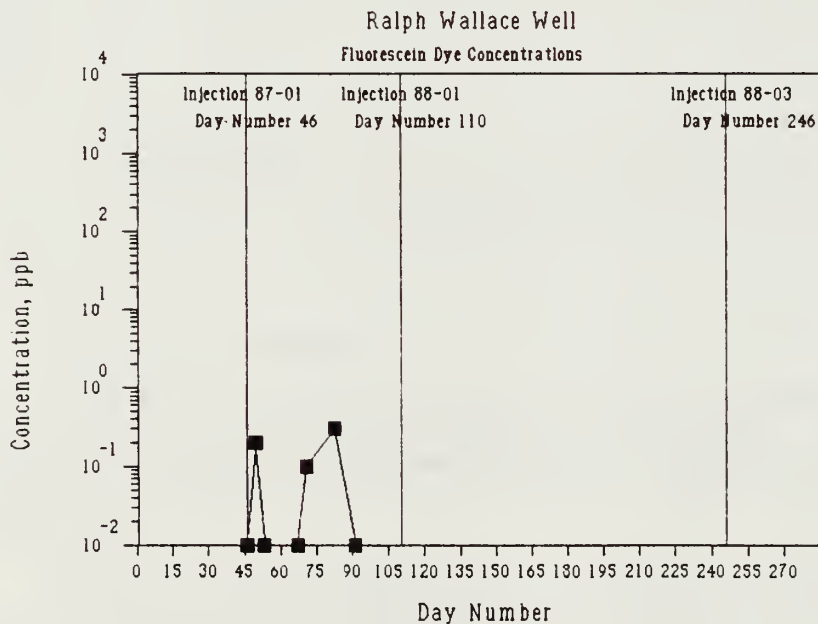
Legend: Pos= Positive dye trace; NS= Not sampled during this trace; ND= No dye detected.

Station 1. Blaine Young Well.

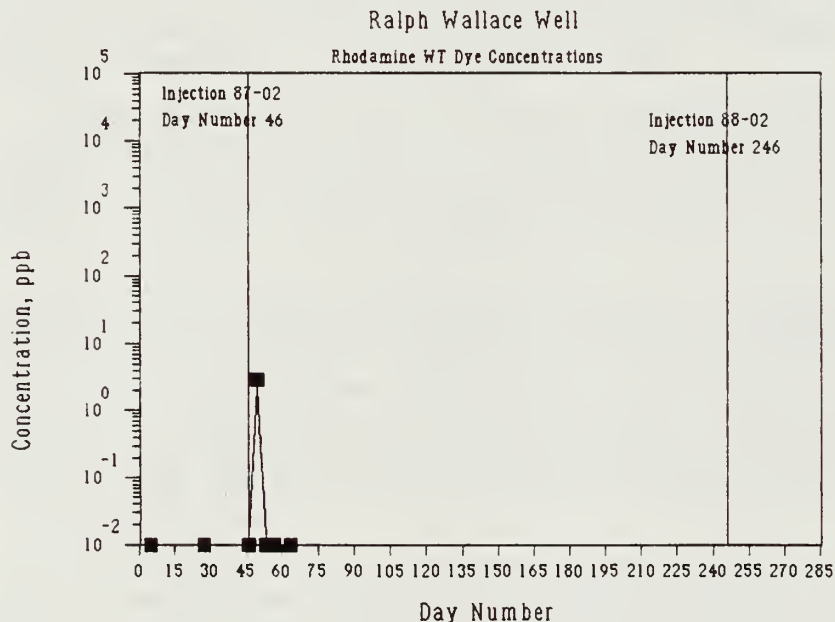
A private drinking water well in Pindall in the NE SE of Section 10, T16N, R18W. Water level elevation of the well is about 1,025 feet. It appears that this well receives much of its water from alluvium and residuum in the Clear Creek Valley. This well was one of four wells in Pindall which received dye from Trace 86-01 (Holder Sinkhole). A sampler in place at this well for the period February 20 to 23, 1986, was moderately positive for fluorescein. This well is located 5,250 feet from the injection site for Trace 86-01. It was sampled in the 1987-1988 tracing program only in conjunction with Traces 87-01 and 87-02.

Station 2. Ralph Wallace Well.

A private drinking water well in Pindall in the SW NE of Section 3, T16N, R18W. Water level elevation in this well is about 1,025 feet. This well apparently receives much of its water from alluvium and residuum in the Clear Creek Valley.



The Ralph Wallace Well was sampled only in conjunction with traces 87-01 (Clear Creek downstream of Wiley Moore Spring) and 87-02 (Kilburn Cemetery Sinkhole); it received dye from both of these injections. Had this well been sampled in conjunction with trace 86-01 (Holder Sinkhole), it is likely that dye from that trace would have been recovered from this well.



Station 3. SPG Well

This is a rural water district well located southeast of Pindall. The well is in the SE SW of Section 2, T16N, R18W. The water level elevation in this well was 865 feet msl in January, 1982. The total depth of the well is 2,170 feet; the top of the well is in the Boone Formation.

One of the major lineaments in the study area is oriented along a portion of the Clear Creek valley southeast of Pindall. The SPG Well, the public water supply for three communities, was intentionally located at the intersection of this lineament and an intersecting fracture trace in an effort to maximize water yields (Ogden, 1980).

The SPG Well is located on a low terrace in a losing stream segment of Clear Creek. The well contains 500 feet of pressure grouted casing; the total depth of the well is 2,170 feet. At the time of well completion in January, 1982, the static water level in the well was 275 feet below the surface (the elevation of the static water level was thus 865 feet). The elevation of the bottom of the casing is 640 feet. While there can always be problems with the leakage integrity of any pressure grouted casing, we have no reason to suspect any significant problems with the casing or grouting in the SPG Well.

Water from the SPG well is chlorinated prior to distribution. During our groundwater tracing work we sampled water from this well at the nearest private connection. An outside hydrant was allowed to flow about at a rate of about 1 gallon per minute; the flow was passed through a packet of activated charcoal.

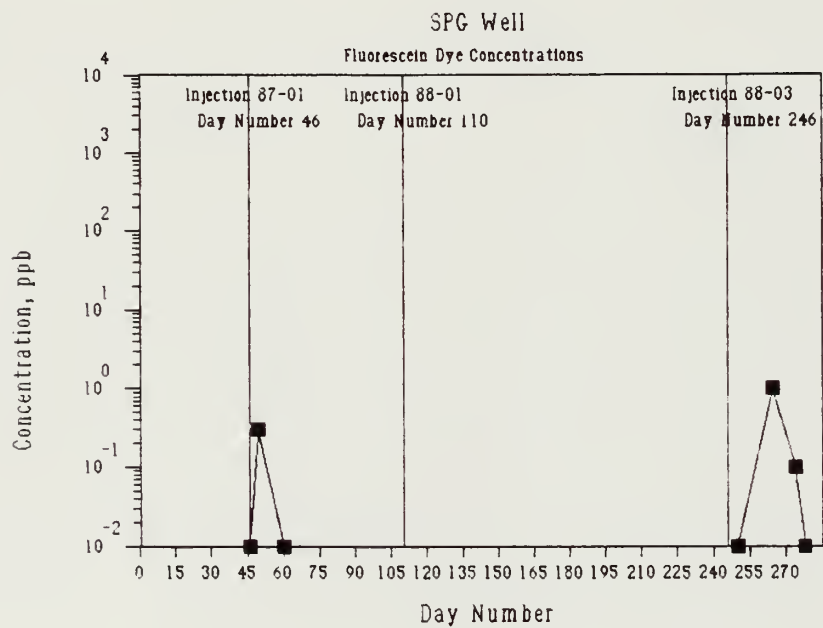
Dyes from injections 87-01 (Clear Creek downstream of Wiley Moore Spring), 87-02 (Kilburn Cemetery Sinkhole), and 88-03 (Clear Creek downstream of Jack Keith Spring) were recovered from the SPG Well. The concentrations were always small, in part due to the fact that chlorination destroys some of the tracer dyes. The presence of tracer dyes in this well demonstrates that groundwater circulation extends to more than 500 feet below the floors of major losing stream valleys in the study area.

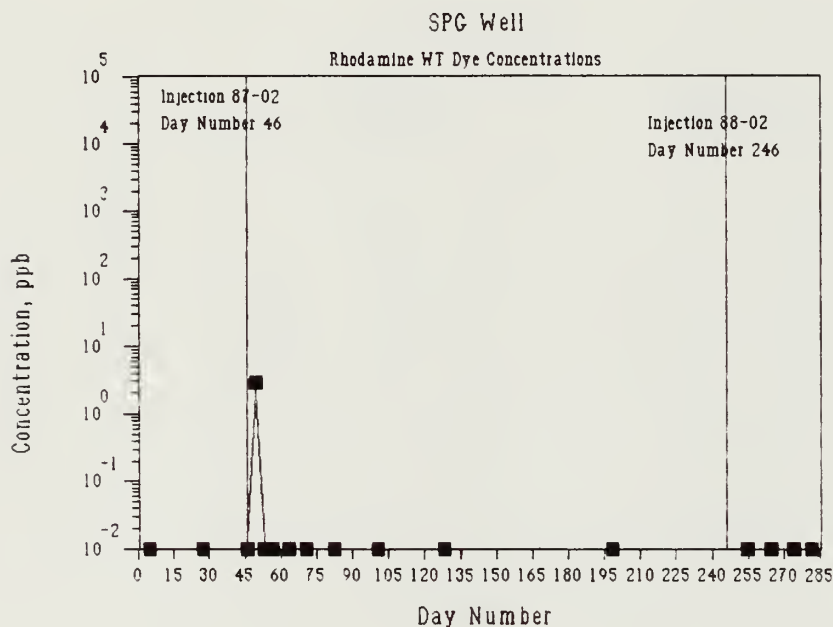
The recovery of dye at the SPG Well from three separate injections clearly demonstrates that deep and rapid groundwater circulation occurs within the study area. Data on these three traces are shown in Table 9. The reader should keep in mind that the surface elevation of the SPG Well is 1140 feet, and the elevation of the bottom of the pressure grouted casing is 640 feet. For comparison, the elevation of Mitch Hill Spring is 720 feet.

Table 9

Summary of Dye Recoveries at the SPG Well.

Injection Site	Surface Elevation of Injection Site	Time of First Dye Arrival at SPG Well	Straight Line Distance to SPG Well
87-01 Losing segment of Clear Cr. below Wiley Moore Spring	1,095 ft.	Within 7 days	1,600 ft.
87-02 Sinkhole nr. Mill Cr. Fault	1,240 ft.	Within 7 days	12,200 ft.
88-03 Losing segment of Clear Cr. below Jack Keith Spring	1,005 ft.	13 to 24 days	10,600 ft.



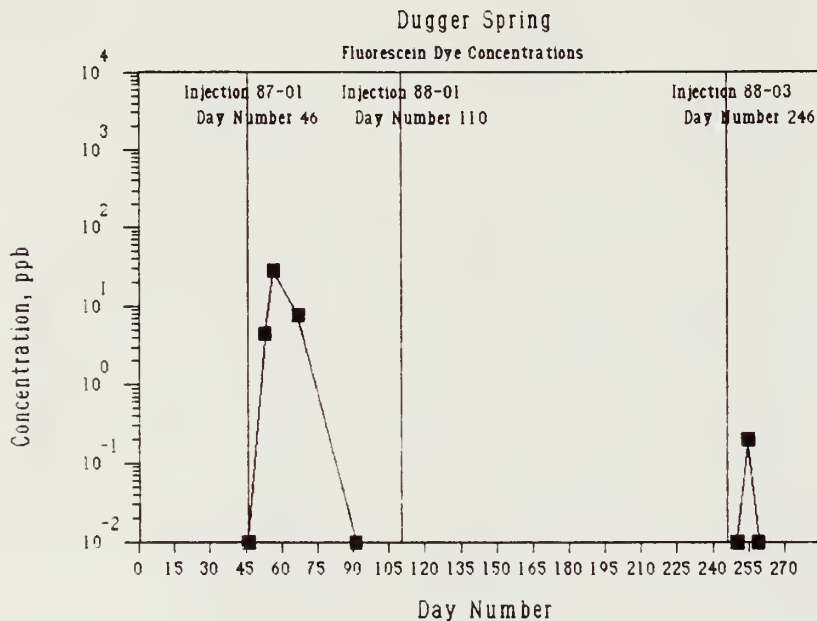


Station 10. Dugger Spring

This is a large spring in the Clear Creek topographic basin. It is located in the NW NW Sec. 21, T17N, R18W at an elevation of 920 feet. The spring is also known as Rockhole Spring. The spring discharges from the St. Peter Sandstone-Everton Formations.

Dye from Trace 87-01 (Clear Creek downstream of Wiley Moore Spring) was recovered from this spring. None of the other traces, including Trace 88-03 (Clear Creek downstream of Jack Keith Spring), was recovered from this spring.

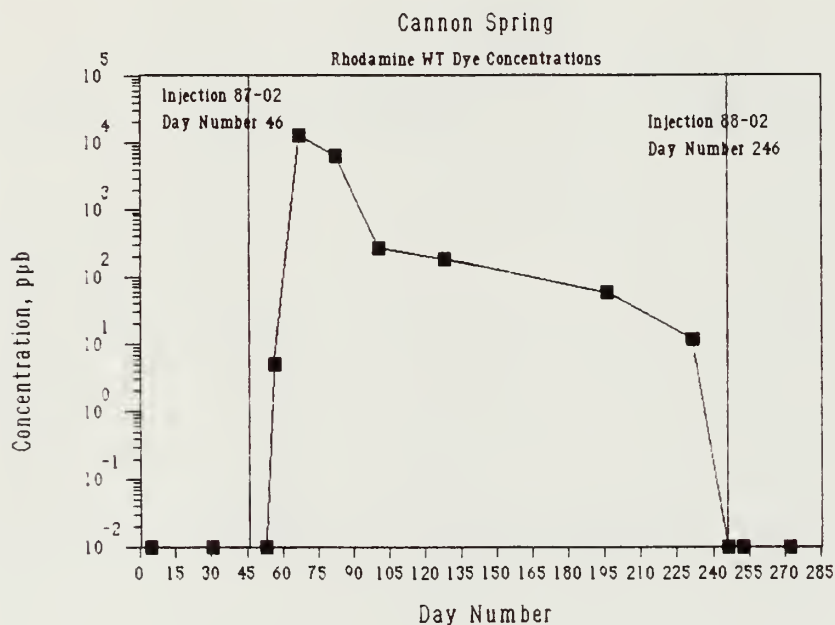
Trace 87-01 indicates that the community of Pindall contributes some recharge water to Dugger Spring during wet and moderately wet weather conditions. Trace 88-03, which involved a dye injection at a point about a mile north of Pindall, demonstrated that the community of Pindall lies outside the recharge area for Dugger Spring during dry and moderately dry weather conditions.



Station 12. Cannon Spring

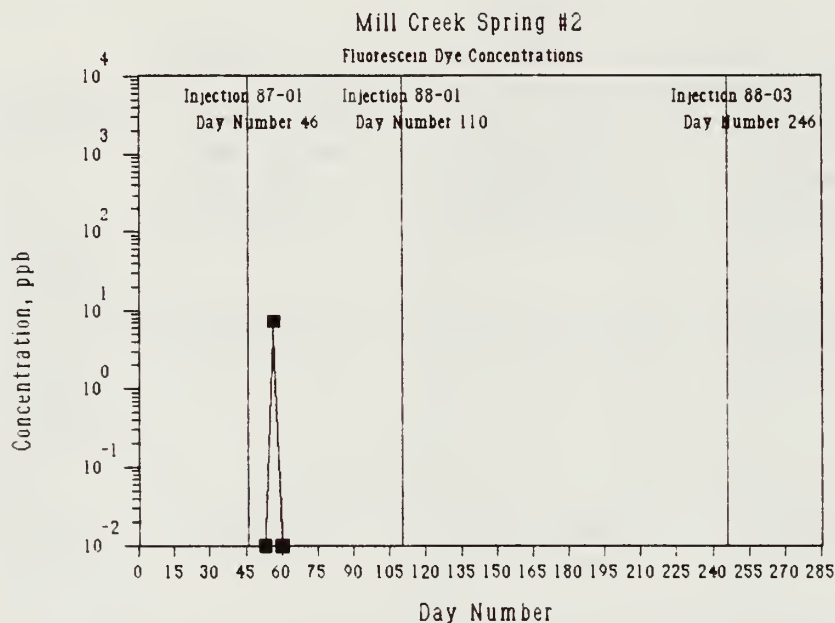
Cannon Spring is located in the Boone Formation immediately north of the Mill Creek Fault. The spring is located in the SW NW Sec. 13, T16N, R18W at an elevation of 940 feet.

Dyes from traces 86-01 (Holder Sinkhole) and 87-02 (Kilburn Cemetery Sinkhole) were recovered from Cannon Spring.



Station 14. Mill Creek Mine Spring

This spring is located on the St. Joe Fault in close proximity to formerly-operated mines. The spring is in the NE NE Sec. 18, T16N, R17W; the elevation is 800 feet. Dye from Trace 87-01 (Clear Creek downstream of Wiley Moore Spring) was recovered from this spring. Mill Creek Mine Spring (which is also known as Mill Creek Spring #2) was not sampled in conjunction with Trace 86-01 (Holder Sinkhole).



Station 16. Mitch Hill Spring

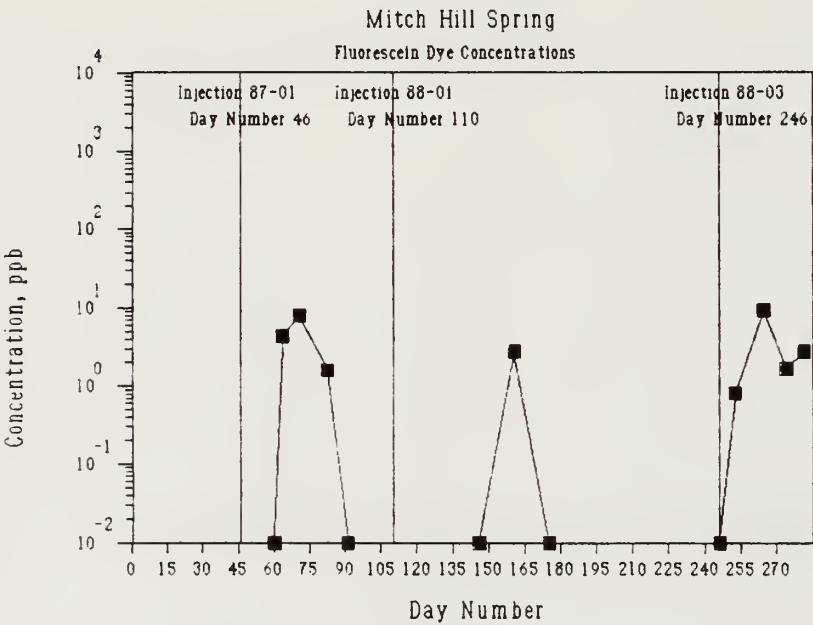
This spring was the primary focus of the present study. Mitch Hill Spring is a major tributary to the Buffalo National River. The spring is located in the NE NW Sec. 25, T16N, R19W. The elevation of the spring is about 720 feet; there are a number of discharge points for the spring. The spring discharges from the St. Peter Sandstone-Everton Formation.

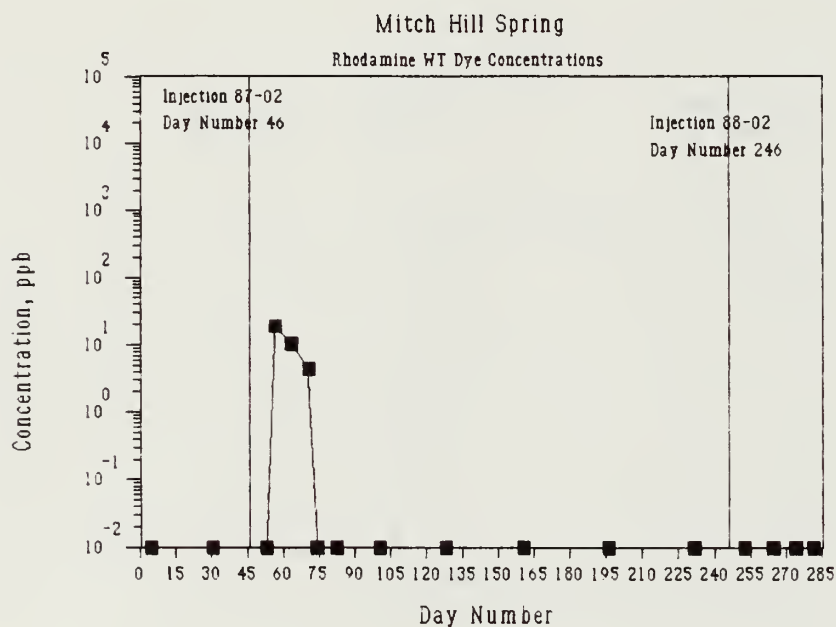
The flow of Mitch Hill Spring has been measured on three occasions. The flow was 13.2 cfs on May 31, 1986; 7.4 cfs on July 9, 1986; and 1.92 cfs on August 12, 1987. The first two measurements were by T. Aley of the Ozark Underground Laboratory and were made just upstream of the mouth of the spring branch. The 1987 measurement was by the National Park Service and was made just upstream of an old concrete structure on the spring branch; there may have been some spring discharge downstream of this gaging station.

Dye from five of the six groundwater traces conducted in the study area has been recovered from Mitch Hill Spring. The results are summarized in Table 10.

Table 10
Summary of Dye Recoveries at Mitch Hill Spring.

Injection Site	Surface Elevation of Injection Site	Time of First Dye Arrival at Mitch Hill Spring	Straight Line Distance to Mitch Hill Spring
86-01 Holder Sinkhole	1,175 ft.	About 61 days	23,500 ft.
87-01 Losing segment of Clear Cr.	1,095 ft.	14 to 21 days.	28,700 ft.
87-02 Sinkhole nr. Mill Cr. Fault	1,240 ft.	7 to 14 days	17,800 ft.
88-01 Hurricane Mine.	1,060 ft.	36 to 65 days	15,100
88-03 Losing segment of Clear Cr.	1,005 ft.	13 to 24 days	29,000 ft.

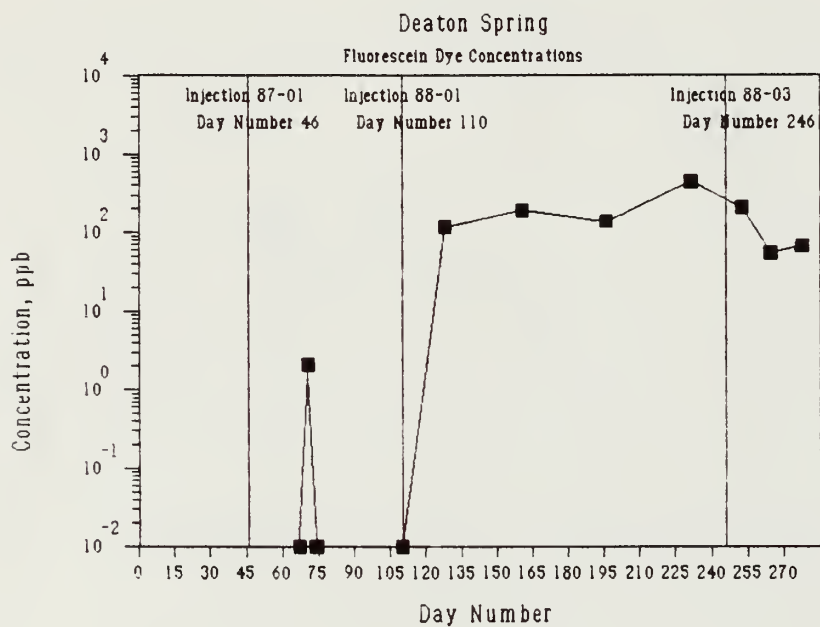


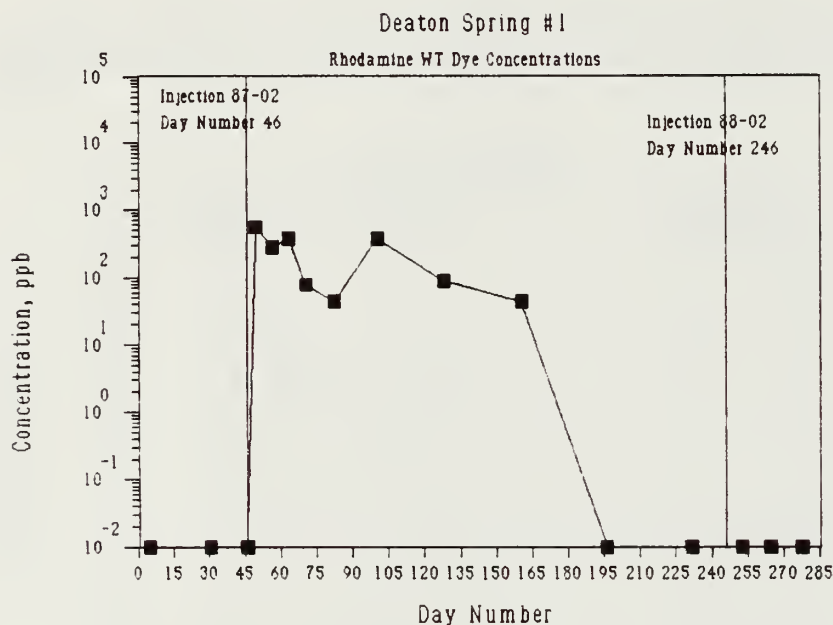


Station 17. Deaton Spring #1

This is a large spring located in the SE NW of Sec. 12, T16N, R19W, at an elevation of 950 feet. The spring discharges from the Boone Formation and is located on or near the St. Joe Fault. The spring formerly supplied water for processing operations at the Hurricane Mine.

Dyes from Traces 87-01 (Clear Creek below Wiley Moore Spring), 87-02 (Kilburn Cemetery Sinkhole), and 88-01 (Hurricane Mine) were recovered from Deaton Spring #1.





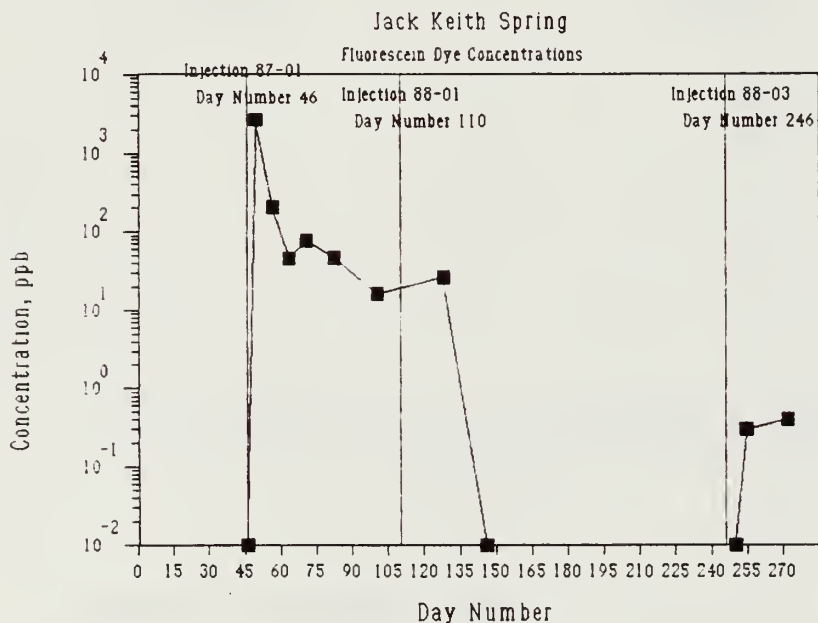
Station 19. Jack Keith Spring

This spring is located slightly less than a mile northwest of Pindall. The spring is in the NW SW Sec. 34, T17N, R18W, at an elevation of 1,020 feet. The spring discharges at the contact of the Boone and St. Peter-Everton Formations.

The spring has large discharges during about six months of the year; flows of at least 5 or 10 cfs are common during this period. During drier periods of the year the spring ceases flow. A few days before flow from the spring ceases the entire flow from this spring sinks in a losing stream segment of Clear Creek; the losing stream segment extends from just downstream of the spring to perhaps 1,500 feet downstream of the spring. Trace 88-03 was injected in this losing stream segment.

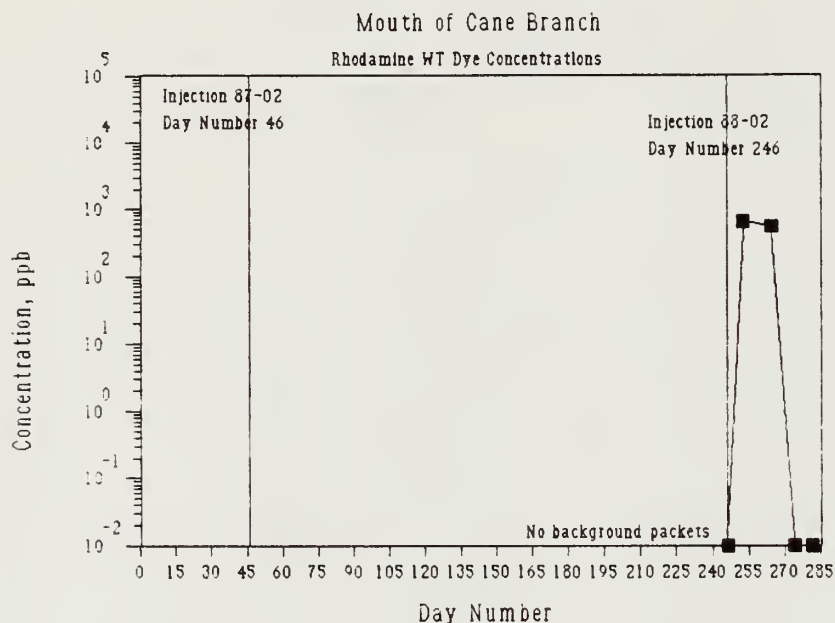
The spring was formerly an important source of local drinking water supplies. Some residents report that the spring formerly flowed for a substantially longer period of the year than is now the case. Some reports suggest that the change in flow conditions occurred at about the time that the SPG Well was put into operation.

Dyes from Traces 86-01 (Holder Sinkhole) and 87-01 (Clear Creek downstream of Wiley Moore Spring) have been recovered from Jack Keith Spring.



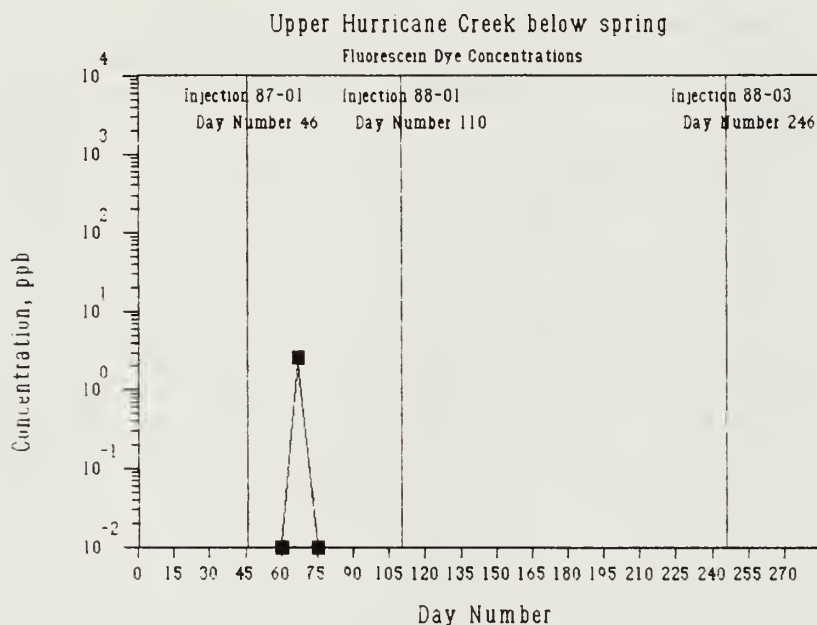
Station 23. Mouth of Cane Branch.

This spring-fed sampling station is located in the SE SE of Sec. 31, T16N, R18W at an elevation of 735 feet. This station was sampled only in conjunction with Traces 88-02 (Cave Spring Branch) and 88-03 (Clear Creek downstream of Jack Keith Spring). The only dye recovered at this station was from Trace 88-02. This trace served to provide an eastern boundary for the Mitch Hill Spring recharge area.



Station 25. Hurricane Spring.

This sampling station is located in the NE NW of Section 7, T16N, R18W at an elevation of about 1,080 feet. It is located on or near the St. Joe Fault. The only dye recovered at this station was from Trace 87-01 (Clear Creek downstream of Wiley Moore Spring). The elevation of the dye injection site was only 15 feet higher than the elevation of this sampling station. However, the groundwater elevations within the area of the St. Joe and Mill Creek Faults undoubtedly rises substantially following storm periods and can thus give a distorted picture of groundwater gradients in the area.



Station 26. Paul Holder Well

This private drinking water well is located in the NE SW of Section 10, T16N, R18W. The water level elevation in the well was 1,099 feet on July 19, 1985. Dye from Trace 86-01 (Holder Sinkhole) was recovered from this well with the first dye recovery occurring within 5 days of dye injection.

Table 11 is developed from the driller's records on the Paul Holder Well. The surface elevation of the well is 1,225 feet. Note that the well passed through six cavities with a total vertical cavity dimension of 57 feet. The well penetrates the Boone Formation and the underlying St. Peter-Everton Formations.

Table 11. Driller's Records on Paul Holder Well

Distance Below Surface (Ft.)	Material*	Cavity Height (Ft.)
0-23	Dirt and sand rock	---
23-26	Solid rock	---
26-40	Cavity	14 ft
40-44	Solid rock	---
44-60	Cavity	16 ft.
60-66	Rock	---
66-83	Cavity	17 ft.
83-114	Rock	---
114-116	Cavity	2 ft.
116-122	Rock	---
122-128	Cavity	6 ft.
128-159	Rock	---
159-161	Water in cavity	2 ft.
161-185	Rock	---

Well initially cased to 84 feet (at time of Trace 86-01). Now cased to about 140 feet to keep mud and rocks from damaging the pump.

* Material terminology is that of the driller.

Station 27. Virgel Henson Well.

This private drinking water supply well is located in Pindall in the SE NW Section 3, T16N, R18W. The water level elevation in the well is about 1,025 feet. This well was sampled only in conjunction with Trace 86-01 (Holder Sinkhole). This was one of four wells in Pindall where dye was recovered during a pumping program conducted for the period from 38 to 41 days after the dye injection.

Station 28. Ernest Herron Well

This private drinking water supply well is located in Pindall in the NE NW Section 3, T16N, R18W. The water level elevation in the well is about 1,025 feet. This well was sampled only in conjunction with Trace 86-01 (Holder Sinkhole). This was one of four wells in Pindall where dye was recovered during a pumping program conducted for the period from 38 to 41 days after the dye injection.

Station 29. Rachel Nichols Well

This private drinking water supply well is located in Pindall in the SE NW Section 3, T16N, R18W. The water level elevation in the well is about 1,025 feet. This well was sampled only in conjunction with Trace 86-01 (Holder Sinkhole). This was one of four wells in Pindall where dye was recovered during a pumping program conducted for the period from 38 to 41 days after the dye injection.

Interpretation of Groundwater Tracing Results

Figure 2 depicts the results of the six groundwater traces on an 8 1/2 by 11 inch map. A larger map, intended to aid those needing more precisely identified boundaries, is found in the pocket at the end of this report. Arrows are drawn schematically from the points of dye injection to the points of dye recovery. The six dye injections resulted in 26 separate dye recoveries from eight springs and seven wells in the area. Because of space limitations, each dye injection shown on Figure 2 is given a single-digit sequential reference number. Injection site 1 is site 86-01, the Holder Sinkhole. Injection site 2 is site 87-01, the Clear Creek site downstream of Wiley Moore Spring. Injection site 3 is site 87-02, the Kilburn Cemetary Sinkhole. Injection site 4 is site 88-01, the Hurricane Mine. Injection site 5 is site 88-02, the Cave Spring Branch. Finally, Injection site 6 is site 88-03, Clear Creek downstream of Jack Keith Spring.

Some spring and well locations in the study area are of special significance. Mitch Hill Spring is located at the lowest elevation of any of the dye recovery sites. Based upon mapping by McKnight (1935), Cannon Spring is located on or very near the Mill Creek Fault and Deaton Spring #1 and Mill Creek Mine Spring are both located on or near the St. Joe Fault. The SPG Well is located on or near the intersection of a lineament and a fracture trace (Thomson, 1985). This well was intentionally located at this intersection in an effort to maximize water yields (Ogden, 1980).

Our groundwater tracing has shown that directions of some groundwater flow in the study area apparently change with changes in hydrologic conditions. This is indicated by two observations.

First, dye injection 86-01 (Holder Sinkhole) is located near the eastern boundary of the once proposed Pindall Landfill. Three monitoring wells were drilled near the perimeter of the proposed landfill and water levels in these wells were measured. Let us assume that these three monitoring wells provide a general depiction of the orientation of the water table; this is an admittedly questionable assumption in a karst area. However, what we find from water level data on the three wells is that, during wet-weather conditions, the apparent water table beneath the landfill area slopes northward (away from the Mill Creek Graben). During dry-weather conditions, the orientation of the water table is reversed almost 180 degrees; it slopes southward (toward the Mill Creek Graben) under these conditions.

PINDALL LANDFILL SITE ARKANSAS

DYE-TRACE RESULTS

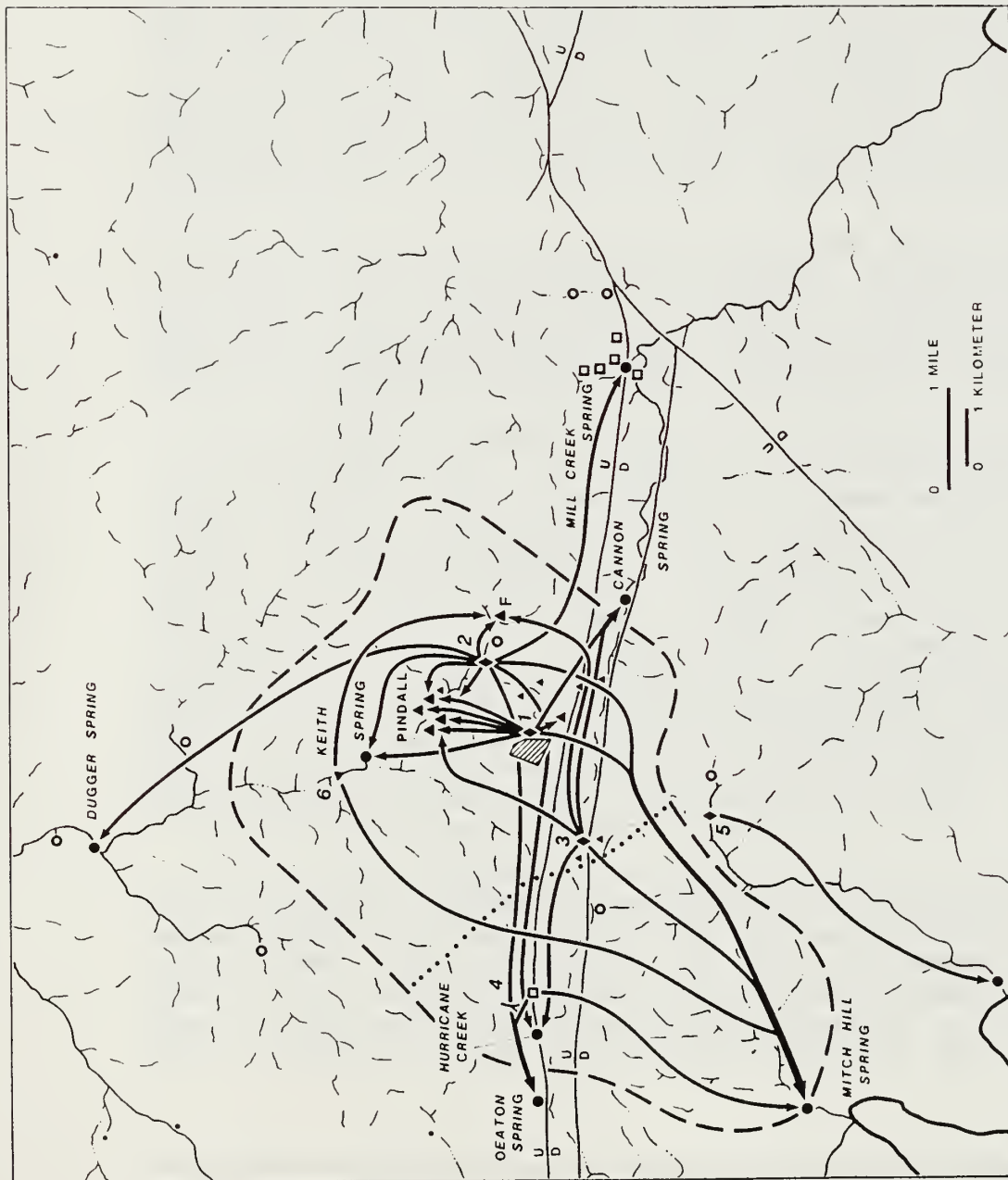
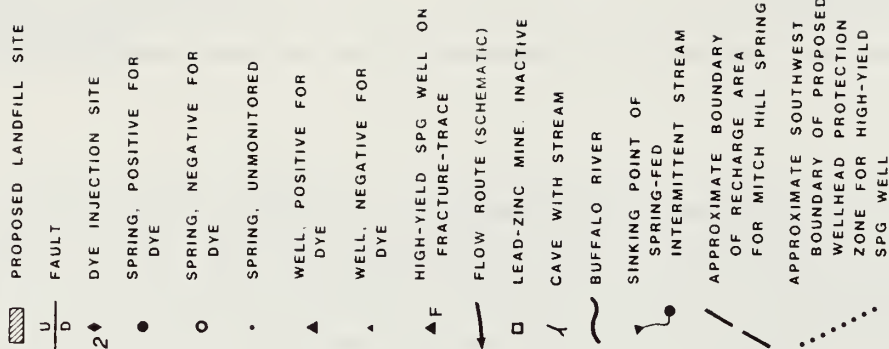


Figure 2. The Study Area and Successful Groundwater Traces

The second example of a change in groundwater flow directions with changes in hydrologic conditions is provided by Jack Keith Spring. Two successful groundwater traces to this spring (Injections 86-01 and 87-01) demonstrate that most of the recharge area for this spring lies south of the spring, thus the dominant direction of groundwater flow to this spring is northward. Injection 88-03 was made at a site about 1100 feet north of Keith Spring; the injection site was the point at which waters from Keith Spring were sinking into the channel of Clear Creek. None of the dye injected at this site was recovered from springs to the north of the injection site (including Dugger Spring which received dye from Injection 87-01). Instead, the dye from Injection 88-03 was recovered at Mitch Hill Spring (located to the southwest of the injection site), and at the SPG Well (located southeast of the injection site).

Large volumes of water enter the groundwater system along the Mill Creek Graben during periods of wet weather. The stream channel of Mill Creek, which traverses a major segment of the graben, has high permeability and is supplied with large volumes of runoff water. One would thus expect appreciable increases in water level elevations along and near the Mill Creek Graben during storm periods.

Our groundwater tracing has shown that about 4.7 miles of the Mill Creek Graben lies in the recharge area for Mitch Hill Spring. Surface stream elevations in the portion of the graben supplying water to Mitch Hill Spring range from 950 feet to about 1,250 feet. The elevation of Mitch Hill Spring is 720 feet; this is one of the largest springs in the Buffalo River Basin. The flow of this spring was 13.2 cubic feet per second (cfs) on May 31, 1986; it was 7.4 cfs on July 9, 1986; and it was 1.92 cfs on August 12, 1987. Groundwater gradients along solutional conduits feeding karst springs are often very gentle (gradients of only one or two feet per thousand feet have been noted). In view of this, and the fact that the distance from the graben to Mitch Hill Spring ranges from 14,000 to 30,000 feet, water levels in the graben could be substantially lowered during dry weather conditions by water discharges through Mitch Hill Spring.

Three other springs also drain those portions of the Mill Creek Graben within the delineated recharge area for Mitch Hill Spring. Deaton Spring #1 is located west of the delineated Mitch Hill Spring recharge area. Cannon Spring and Mill Creek Mine Spring are both located east of the delineated Mitch Hill Spring recharge area. All three of these springs are located in close proximity to the St. Joe Fault. Dye from injections 87-01, 87-02, and 88-01 was recovered

from Deaton Spring #1. Dye from injections 86-01 and 87-02 was recovered from Cannon Spring, and dye from injection 87-01 was recovered from Mill Creek Mine Spring. It is noteworthy that injection 87-02, which was located on or near the Mill Creek Fault and near the center of the delineated recharge area for Mitch Hill Spring, yielded dye to springs located both east (Cannon Spring) and west (Deaton Spring #1) of the Mitch Hill Spring recharge area boundary.

Combining wet-weather and dry-weather conditions, and other factors noted above, it is clear that there could be appreciable groundwater level fluctuations in the graben. We believe this to be the actual case. Furthermore, it is likely that there are multiple solutional channel flow routes which can be utilized by waters moving from the Mill Creek Graben to Mitch Hill Spring. These conduits will occur at different points and different elevations and will have different flow capacities.

We anticipate that water level elevations in these recharge areas vary substantially with seasonal changes; this type of situation is commonly encountered in karst areas. As an illustration, water level fluctuations can exceed 40 meters in 24 hours in a well in the recharge area for Ombla Spring in Yugoslavia; seasonal fluctuations in this well can exceed 130 meters (Milanovic, 1981). Rapid and major changes in water level elevations are undoubtedly an important mechanism for explaining apparent reversals in groundwater gradients in the study area in Arkansas.

Fracture traces and lineaments are readily discernable on aerial photos of the study area. There is extensive literature (such as Parizek, 1976; Wagner et al., 1976) indicating that fracture traces and lineaments in carbonate rocks are typically areas of greater well yields. In the Ozarks, these features are commonly associated with springs. In northwest Arkansas, groundwater supplies along lineaments and fracture traces are commonly more susceptible to contamination than are groundwaters in adjacent areas (Wagner et al., 1976).

Thomson (1985) mapped lineaments and fracture traces in a portion of the study area. Many of these features parallel the St. Joe and Mill Creek Faults or else have a northeasterly trend.

One of the major lineaments in the study area is oriented along a portion of the Clear Creek valley southeast of Pindall. The SPG Well, the public water supply for three communities, was intentionally located at the intersection of this lineament and an intersecting fracture trace in an effort to maximize water yields.

The SPG Well is located on a low terrace in a losing stream segment of Clear Creek. The well contains 500 feet of pressure grouted casing; the total depth of the well is 2,170 feet. At the time of well completion in January, 1982, the static water level in the well was 275 feet below the surface (the elevation of the static water level was thus 865 feet). The elevation of the bottom of the casing is 640 feet. While there can always be problems with the leakage integrity of any pressure grouted casing, we have no reason to suspect any significant problems with the casing or grouting in the SPG Well.

Water from the SPG well is chlorinated prior to distribution. During our groundwater tracing work we sampled water from this well at the nearest private connection. An outside hydrant was allowed to flow about at a rate of about 1 gallon per minute; the flow was passed through a packet of activated charcoal.

Dye from injections 87-01, 87-02, and 88-03 was recovered from the SPG Well. The concentrations were always small, but chlorination does destroy some of the tracer dyes. The presence of tracer dyes in this well demonstrates that groundwater circulation extends to more than 500 feet below the floors of major losing stream valleys in the study area.

Some workers in the Ozarks have assumed that each identified geologic mapping unit typically represented a separate aquifer. Sometimes units are grouped to produce two or more superimposed aquifers. While there may be hydrogeologic utility in this characterization, it frequently leads engineers and geologists into the routine presumption of negligible vertical interconnection of groundwater systems in the region.

The recovery of dye at the SPG Well from three separate injections clearly demonstrates that deep and rapid groundwater circulation occurs within the study area. The reader should keep in mind that the surface elevation of the SPG Well is 1140 feet, and the elevation of the bottom of the pressure grouted casing is 640 feet. For comparison, the elevation of Mitch Hill Spring is 720 feet.

In general, static water level elevations in wells in the study area tend to decrease with increases in the depth of the well. As an illustration, the reported static water level in the SPG Well at the time of well completion was at elevation 865 feet. Private wells in the vicinity with minimal amounts of casing have water levels which are at least 100 feet higher than this.

What is the nature of the flow system which conveys waters from the surface into the SPG Well with the rapidity discovered in our tracing work? We are dealing with straight line velocities as great as 1,750 feet per day or more. This obviously requires a solutionally widened system of karst conduits of major lateral extent. The groundwater tracing data clearly indicate that such a system exists within the Mill Creek Graben and/or along the boundary faults. The SPG Well is located about 4,900 feet from nearest point on the Mill Creek Graben. Solutional openings along mapped fracture traces and lineaments in the area may provide much or all of the connections between the graben and the SPG Well.

It seems likely that deep circulation of groundwater in the study area occurs primarily at localized sites along or near faults, lineaments, and fracture traces. If this is the case, there should be shallow groundwater flow moving toward those faults, lineaments, and fracture traces which provide zones of deeper water circulation. With such a system, flow directions could readily change with changes in the flow rates of the various solutional conduits or with the total volume of flow. Based upon mapping of lineaments and fracture traces in a major portion of the study area (Thomson, 1985), there are essentially no areas located more than 1,200 feet from an identified fault, lineament, or fracture trace. If faults, lineaments, and fracture traces provide localized sites for deep groundwater circulation, the area would be characterized by an extremely complex groundwater flow system. Furthermore, these fracture zones would create a system in which radial groundwater flow patterns from localized groundwater input points would be a common situation.

A question for the future is whether the groundwater system we have described is a unique occurrence, or whether it is a common occurrence in the Ozarks which is depicted uncommonly well in the study area. We suspect the latter, and urge resource managers to anticipate similar situations elsewhere in the Ozarks and in other karst areas. It should be noted that, while mapped faults are not particularly common in the karst regions of the Ozarks, lineaments and fracture traces are almost always present.

Delineation of the Recharge Area for Mitch Hill Spring

The delineated recharge area for Mitch Hill Spring is shown on the small map in Figure 2; it is also shown on the larger map in the pocket at the end of this report. The delineated recharge area for Mitch Hill Spring comprises 20.8 square miles. Our dye tracing results

demonstrate that 13.4 square miles of this area also contributes water to the SPG Well, a rural water district well which is the sole public water supply for three communities in the region.

The recharge area delineations are based upon the results of the six groundwater traces conducted in the study area. Lands topographically tributary to sites which have been shown to contribute waters to Mitch Hill Spring are included in the recharge area delineations. In addition, we have included areas topographically tributary to losing stream segments near (but somewhat downstream of) dye injection sites 88-01 and 88-03; it is our view that this is a prudent interpolation of the data. The eastern boundary of the Mitch Hill Spring recharge area in the Mill Creek Valley is a "best estimate" based upon our understanding of groundwater flow along the fault zone and the observation that the portion of Mill Creek within the delineated Mitch Hill Spring recharge area loses substantial quantities of water into the groundwater system.

It should be noted that the proposed Pindall landfill (which has now been denied a permit because of the impacts it would have had on Mitch Hill Spring and the Buffalo National River) is located near the center of the Mitch Hill Spring recharge area. This proposed landfill is also within the area which should be designated as the wellhead protection zone for The SPG Well. During the design and review process, the landfill proponents and Arkansas regulatory agencies essentially ignored hydrologic assessment approaches appropriate to karst terranes; reliable monitoring is discussed by Quinlan and Ewers (1986). Had it not been for third party studies of the proposed landfill, and associated legal action, a landfill would have been located in the midst of an area which recharges water to a public water supply well and a major spring feeding the Buffalo National River.

OPTICAL BRIGHTENER SAMPLING

Methods

Optical brighteners are fluorescent white dyes present in laundry soaps and detergents. Their presence in water supplies is evidence of sewage contamination. Their utility as a reconnaissance tool for detecting sewage in karst groundwater has been discussed by Aley (1985).

The analysis outlined by Aley (1985) utilized cotton samplers placed for a number of days in the water to be tested. After recovery of the samplers and cleaning, the samplers were examined under an ultraviolet light for visual detection of optical brighteners. We have since improved on this method; our analysis now uses a Shimadzu RF-540 spectrofluorophotometer for detecting optical brighteners. The analysis uses a synchronous scan of both excitation and emission spectra from 367 nm to 487 nm with a 17 nm separation between excitation and emission wavelengths. This analysis produces a graphical chart of fluorescence intensity. Using this protocol, a fluorescence peak on a cotton sampler will be detected at about 420.9 nm if optical brighteners are present in the sampler. The fluorescence peak for optical brighteners on cotton samplers, plus or minus two standard deviations, will range from 418.7 to 423.1 nm.

Appendix B contains a six-page guide to the interpretation of RF-540 charts. This guide is relevant to optical brighteners as well as to Rhodamine WT and fluorescein dyes. Appendix D includes all Shimadzu RF-540 analysis graphs for optical brightener sampling in the study area.

Optical brightener results are qualitatively divided into four categories. The definitions of the categories are essentially the same as those used in Aley (1985). They are as follows:

Strongly positive for optical brighteners: The sampling cotton is entirely white; the color is brilliantly white. This represents waters strongly contaminated with sewage or sewage effluents.

Moderately positive for optical brighteners: The sampling cotton is entirely, or nearly entirely, white; the color is not brilliantly white. This represents waters moderately contaminated with sewage or sewage effluents.

Weakly positive for optical brighteners: Less than 75% of the sampling cotton has been whitened, but optical brighteners are visibly present in the sample. The cotton is not brilliantly white. This represents waters weakly contaminated with sewage or sewage effluents.

Non-detectable for optical brighteners: Optical brighteners are either not detectable or are absent. This represents waters either uncontaminated with sewage or else contaminated at concentrations less than our detection limits.

Results

Optical brightener sampling was conducted at 18 sampling stations in the study area. The sampling stations included Mitch Hill Spring and a number of other springs which are ultimately tributary to the Buffalo National River. Samplers were placed at all stations on November 23, 1987 and were collected for analysis on November 30, 1987. The results are shown in Table 12. Sampling station numbers and locations are the same as listed in Table 1.

Table 12. Summary of Optical Brightener Sampling
November 23 to 30, 1987

Station Number and Name	Optical Brightener Results
1. Blaine Young Well	Weakly Positive; fluorescence peak at 419.4 nm.
2. Wallace Well	None Detected
3. SPG Well	None Detected
4. Wiley Moore Spring	Weakly Positive; fluorescence peak at 422.0 nm.
5. Bull Hollow Spring	None Detected
7. Cave Spring	None Detected
8. Odie Moore Spring	Weakly Positive; fluorescence peak at 421.3 nm.
9. Murray Spring	Weakly Positive; fluorescence peak at 421.7 nm.
10. Dugger Spring	None Detected
12. Cannon Spring	None Detected
13. Mill Creek (St. Joe) Spr.	None Detected
14. Mill Creek Mine Spring	None Detected
16. Mitch Hill Spring	Weakly Positive; fluorescence peak at 422.8 nm.
17. Deaton Spring #1	None Detected
18. Jamison Spring	None Detected
19. Jack Keith Spring	None Detected
20. Chinquapin Spring	None Detected
25. Hurricane Spring	Moderately Positive; fluorescence peak at 420.5 nm.

Interpretation of Optical Brightener Sampling Results

The results indicate that most of the springs and wells sampled for the presence of optical brighteners during the period November 23 to 30, 1987, did not contain detectable amounts of these agents. Those stations where optical brighteners were not detected are considered to be sites which were not significantly affected by sewage contaminants during the sampling period.

Optical brighteners were detected at Mitch Hill Spring. In view of the delineated recharge area for this spring and the fact that it includes many homes, this result is not surprising. Hurricane Spring is the only other spring ultimately tributary to the Buffalo River from which optical brighteners were also recovered. The source of these optical brighteners was probably local homes.

It has been our experience that optical brighteners are most likely to be detected in a spring or well during wet periods when appreciable groundwater recharge is occurring. Our sampling was conducted during a moderately wet period in which we were also running a couple of dye traces. It is surprising that Jack Keith Spring was one of the sites where optical brighteners were not detected; the town of Pindall lies in the recharge area for this spring. We anticipate that, had we conducted more extensive sampling, we would have ultimately recovered some optical brightener dyes from Jack Keith Spring.

THREATS TO THE QUALITY OF WATER AT MITCH HILL SPRING

Characteristics of Groundwater Systems in Soluble Rock Areas

Groundwater systems in soluble rock areas have characteristics which must be understood if we are to adequately address groundwater contamination problems. The purpose of this section of the report is to explain how groundwater systems in soluble rock areas (such as the study area) function.

The term "water table" is familiar; the term commonly conveys the impression that the water table is a flat, continuous, and uniform boundary between the zone of saturation (where all voids are filled with water) and the overlying zone of non-saturation. However, the water table in soluble rock areas is not necessarily a flat, continuous, and uniform boundary. Instead, the water table is better visualized as an irregular, sometimes non-continuous, non-uniform boundary between the zones of saturation and non-saturation.

Groundwater recharge is the water which moves from the surface of the land downward to the water table. In soluble rock areas there are two kinds of groundwater recharge. These are: 1) diffuse recharge, and 2) discrete recharge.

Diffuse recharge is the general and relatively slow seepage and percolation of recharge water toward the water table. Diffuse flow, by definition, is not concentrated flow.

Discrete recharge, which could also be called concentrated recharge, is the concentrated and relatively rapid movement of recharge water toward the water table. Discrete recharge is localized; it occurs in discrete areas which could be delineated on a map with the collection of sufficient information. Substantially greater quantities of water per unit area enter the subsurface water system through discrete recharge zones than through diffuse recharge. Furthermore, discrete recharge is more rapid than diffuse recharge.

Discrete recharge is common in soluble rock areas, and is generally restricted to such areas. The reason for this restriction to soluble rock areas is that the hydrologic development and maintenance of discrete recharge zones requires that soil particles and organic material must be transported through the subsurface. This transport is first downward to the water table by groundwater recharge, and then laterally through the groundwater system by groundwater flow.

If soil particles and organic material are to be transported through the subsurface, they must be suspended in the transporting water. This requires that the transporting water must be moving, and that the flow must be at least somewhat turbulent in order to keep the soil particles and organic material in suspension. Without turbulent flow, the suspended material would settle out of the water, and thus could not be transported by the water.

The only groundwater systems where turbulent flow can occur are those where there are significant openings within the groundwater system. In the study area, adequate-sized openings are restricted to the solutionally widened joints, bedding planes, and faults within the soluble rock units, and to some of the soil and residuum which overlies such rock units.

There are three general types of discrete recharge zones. These are: 1) sinkholes, 2) losing streams, and 3) discrete recharge zones which lack surface expression.

Sinkholes are natural depressions in the surface of the land. They drain internally into the groundwater system. Although some sinkholes are due to collapse of underlying cave passages, most sinkholes exist because they are located at points from which substantial volumes of material have been transported into and through groundwater systems. There are some sinkholes in the Mitch Hill Spring recharge area, yet they are relatively rare features in the region.

Discrete recharge zones which lack surface expression are localized areas where substantial volumes of groundwater recharge occur, but where there is no topographic expression of the recharge zones (such as a sinkhole). Even though we often cannot identify the location of the discrete recharge zones which lack surface expression, the behavior of spring systems clearly demonstrates that they occur. There are numerous discrete recharge zones which lack surface expression in the study area.

Groundwater is that portion of subsurface water which is at or below the water table. Groundwater movement is more or less lateral, in contrast to the more or less vertical movement of groundwater recharge.

There are two categories of groundwater in soluble rock areas. These are: 1) water in storage, and 2) water in transit. This distinction is important if we are to have a useful and realistic understanding of groundwater systems in the Mitch Hill Spring study area.

In many groundwater cases, once water moves from groundwater recharge into groundwater, the groundwater is referred to as "water in storage". Typical lateral groundwater movement in many aquifers in the United States is only a few feet per year. Under such conditions, the term "water in storage" is certainly appropriate.

Some groundwater movement in soluble rock lands can be very rapid. Based upon dozens of groundwater traces in soluble rock regions of the Ozarks and elsewhere, it is not uncommon for groundwater in these areas to move laterally for hundreds or thousands of feet per day. This rapidly moving water is in transit, not in storage. Obviously the two classes (water in storage and water in transit) are a continuum, for even the water in storage has some movement. For soluble rock areas, Aley (1977) recommended that waters moving at rates equal to or in excess of one foot per hour should be regarded as "water in transit", and waters moving at rates of less than one foot per hour should be regarded as "water in storage".

Discrete recharge zones contribute almost exclusively to groundwater in transit. Many discrete recharge zones are in effect surface expressions of the underground drainage conduits which move the in-transit component of the groundwater. In order for a discrete recharge zone to develop, suspended materials must be flushed from the recharge zone; such flushing would be unlikely unless the discrete recharge zone had a direct and rapid connection with conduit systems able to transport water with sediments held in suspension.

Most of the groundwater recharge which contributes to water in storage is diffuse recharge. During flood flows along the water in transit conduit systems, there can be movement from the conduit system into the water in storage component of the groundwater system since pressure gradients are created.

Diffuse recharge will also contribute some water to the water in transit component of the groundwater system. However, the majority of the recharge to the water in transit component of the groundwater system is discrete recharge.

Well yields in soluble rock units are generally small. These small yields are commonly associated with water in storage, not with water in transit. Higher water yields occur when wells encounter solutionally enlarge openings which transport water in transit.

There is typically a difference in water quality between water in storage and water in transit. Water in storage tends to have higher concentrations of dissolved calcium carbonate than does water in transit. Water in transit tends to have higher concentrations of bacterial (and presumably viral) contaminants than does water in storage.

The water quality differences between water in storage and water in transit are due primarily to two factors:

- 1) Water in storage has normally been underground longer than water in transit. In general, the longer water is underground, the more material it will dissolve. Bacterial populations decrease substantially with time; in general, the longer water is underground, the lower the concentration of bacterial contamination.
- 2) Water in storage is replenished primarily by diffuse recharge; water in transit is replenished primarily by discrete recharge. Diffuse recharge water is exposed to more effective filtration and adsorption than is discrete recharge. Furthermore, diffuse recharge tends to contain higher concentrations of dissolved calcium carbonate than is contained in discrete recharge.

Water in transit is generally much more subject to contamination or pollution than is water in storage. This does not mean, however, that water in storage is not subject to significant contamination hazards.

Water in transit is more subject to contamination and pollution than is water in storage for the following reasons:

- 1) Discrete recharge is more important in the replenishment of water in transit than it is in replenishing water in storage. Discrete recharge typically provides less effective adsorption and filtration than diffuse recharge.
- 2) Travel rates are more rapid; there is thus less time for bacterial and viral die-off, and less time for oxidation of contaminants.
- 3) With water in storage, there may be effective or fairly effective filtration and adsorption in the aquifer. Based on the data available, we conclude that effective filtration and adsorption within the conduits transporting water in transit is undependable and is generally unlikely.

Water in storage is more subject to long term contamination or pollution than is water in transit. If water in storage becomes contaminated, groundwater supplies can be contaminated for years because of the generally slow movement of water in storage. In

contrast, although water in transit is highly susceptible to contamination and pollution, once the source of contamination is eliminated the system will tend to cleanse itself reasonably rapidly. We thus need to be very much concerned about the hazards of contaminating water in storage; there is no justification for complacency.

Identification and Mapping of Water Quality Hazard Areas

Our hazard area mapping is designed to identify areas which have differing potentials for the introduction into Mitch Hill Spring of serious groundwater contaminants. All hazard area identifications and classifications are based upon water quality impacts upon Mitch Hill Spring; it should be remembered that there are other springs and wells in the region which could also be affected by conditions within the Mitch Hill Spring recharge area since they share portions of this recharge area. The hazard area mapping is based upon our groundwater hydrology work and the discussions in the previous section of this report. We have established four hazard area categories which are identified and explained in the following paragraphs.

Extremely High Hazard Areas. These areas are confined to the identified recharge area for Mitch Hill Spring. For areas topographically tributary to Clear Creek, they are restricted to areas topographically tributary to Clear Creek at points upstream of the mouth of Jack Keith Spring. The Extremely High Hazard areas are losing streams valleys, areas within the Mill Creek Graben, and areas along or within three hundred feet of fault zones, lineaments, fracture traces, or sinkholes. A detailed mapping of lineaments, fracture traces, and sinkholes throughout the study area was beyond the scope of this investigation; however, it is our intention that all such features within the identified area be viewed as extremely high hazard areas.

High Hazard Areas. All High Hazard Areas are confined to the identified recharge area for Mitch Hill Spring. All High Hazard Areas comply with one of the following two conditions:

- 1) They are losing stream segments, faults, lineaments, fracture traces, or sinkholes which are topographically tributary to Clear Creek downstream of the mouth of Jack Keith Spring.
- 2) They are topographically tributary to an Extremely High Hazard Area.

Moderate Hazard Areas. All Moderate Hazard Areas are confined to the identified recharge area for Mitch Hill Spring. All Moderate Hazard Areas lack features which warrant designation as a High Hazard

Area, but are topographically tributary to a High Hazard area. All Moderate Hazard areas are topographically tributary to Clear Creek at points downstream of the mouth of Jack Keith Spring.

Low Hazard Areas. All Low Hazard Areas lie within 0.5 miles of, but outside of, the identified recharge area for Mitch Hill Spring. This designation is a reflection of the natural inaccuracies involved in recharge area delineations.

If future groundwater tracing work conducted by experienced and competent individuals enlarges the delineated boundaries of the Mitch Hill Spring recharge area, it is our recommendation that the hazard area delineations be adjusted in accordance with the modified recharge area boundaries. The recharge area boundaries we have drawn do not include routine buffer or questionable areas, so future work has the potential for enlarging (but not decreasing) the size of the delineated recharge area for Mitch Hill Spring.

Map Sheet 3, in the envelope at the end of this report, presents a hazard area map for the Mitch Hill Spring recharge area.

The Mitch Hill Spring recharge area encompasses 20.8 square miles. Within this area we have also delineated the recharge area for the SPG Well; this area (which could also be called the wellhead protection zone for the SPG Well) encompasses 13.4 square miles. The hazard area classes and delineations for Mitch Hill Spring are also appropriate for those areas which also provide recharge waters for the SPG Well.

Point Sources and Non-Point Sources

Water contamination sources are commonly divided into "point sources" and "non-point sources". As the name indicates, a point source occurs in a very localized area; a wastewater discharge pipe from a city sewage treatment plant is an example of a point source. In contrast, agricultural lands represent a non-point source for contaminants. The division becomes blurred when several point sources are located in a relatively small area. For example, effluents from household septic tanks are routinely considered to be non-point sources of contaminants.

For purposes of this report we have divided potential water contamination sources into "point sources" and "non-point" sources by assuming that point sources are those which are highly localized in nature. Non-point sources are those which are not highly localized. In the following pages we will discuss both point and non-point sources of water contaminants in the Mitch Hill Spring recharge area.

Identification and Assessment of Potential Point Sources of Water Contamination

Potential contamination site #1. Approximately 5.6 miles of U.S. Highway 65 passes through the Mitch Hill Spring recharge area. This is a major north-south route through this portion of Arkansas. About 1.6 miles of Arkansas Highway 235 passes through the Mitch Hill Spring recharge area. This is not a major travel route, yet it does carry substantial local and regional traffic.

Leaks and spills of hazardous truck cargoes can cause substantial problems for groundwater systems and springs in karst areas. Some cargoes are very toxic, while others can severely deplete oxygen in receiving groundwaters or create other water quality problems. The majority of the highway corridors traverse lands mapped as High Hazard or Extremely High Hazard areas. Mitch Hill Spring, as well as the SPG Well, could be significantly affected by leaks and spills along these highways. Some of the most severe potential problem areas are in the Clear Creek Valley at or near points where the highway crosses the stream or immediate tributaries to the stream.

Potential contamination site #2. Quick Stop (Texaco) with 4 fuel pumps and 5 above-ground storage tanks. Located in Pindall.

The introduction of petroleum products into spring systems can present hazards to aquatic life, create undesirable visual impacts, and decrease dissolved oxygen in the water. Significant introduction of petroleum products into spring systems can occur from leaks or spills at petroleum storage sites. We know of no present petroleum leakage problems at either of the two current petroleum storage sites.

There is at least one private well in Pindall which is contaminated with petroleum products. This determination is based upon the strong petroleum odor detectable in the water. The source of this petroleum contamination is unknown.

Potential contamination site #3. J and L Grocery (Conoco) with 4 fuel pumps. Located in Pindall. Diesel fuel is stored above ground; other fuel storage is apparently in underground tanks.

Identification and Assessment of Potential Non-Point Sources of Water Contamination

Potential contamination site #4. Community of Pindall. This community, with a current population of approximately 150, lies within the Mitch Hill Spring recharge area in an area mapped as Extremely High Hazard. Sewage disposal in the community is by septic field systems, which undoubtedly results in at least some groundwater contamination. Our reconnaissance sampling of Jack Keith Spring (which also receives recharge waters from the community of Pindall) did not detect any optical brighteners, yet our experience indicates that these indicators of sewage contamination should be anticipated to discharge from this spring at some times.

Pindall does not appear to be large enough to make a city-wide sewage collection and treatment system an economically viable approach. Furthermore, the valley of Clear Creek (in which Pindall is located) is a losing stream within the Mitch Hill Spring recharge area (and the recharge area for the SPG Well) for at least two miles downstream of town. Disposal of treated wastewaters into this losing stream would create groundwater quality degradation which could easily equal or exceed the existing groundwater contamination problems within Pindall. The best sewage disposal approach for Pindall probably lies in careful siting and operation of septic field systems within the community.

There are two gasoline stations within Pindall; they were discussed as potential contaminants sites 2 and 3.

The J and H Custom Church Furniture Plant is located near the south end of Pindall. They undoubtedly store relatively small volumes of paints, varnishes, and similar materials and produce waste sawdust and similar materials. These activities are not of sufficient magnitude to warrant identification of this plant as a potential contaminants site.

Potential contamination site #5. Proposed Bob Cash Landfill. Proposed for portions of section 9 and 10, T16N, R18W. A permit for the proposed landfill has been denied by the Arkansas Pollution Control and Ecology Commission, and their decision has been upheld by the Circuit Court. The latter decision has been appealed by the landfill proponent.

The proposed site has been the subject of extensive investigations and litigation. The entire site lies within the recharge area for Mitch Hill Spring and within the recharge area for the SPG Well. The entire proposed landfill area is within areas mapped as High Hazard or Extremely High Hazard. Groundwater Trace 86-01 utilized a sinkhole

injection site immediately adjacent to the proposed landfill; dye from the injection was recovered from Mitch Hill Spring and from other springs and several wells in the area.

A detailed discussion of the proposed landfill is beyond the scope of the present investigation. A landfill within the recharge area for Mitch Hill Spring would represent an extremely serious threat to the maintenance of good water quality in Mitch Hill Spring and in the Buffalo River to which this spring discharges.

Discussion of Agricultural Land Use Impacts on Groundwater

Little of the land within the Mitch Hill Spring recharge area is suited for row crop agriculture. Row crop and orchard land uses typically involve much heavier use of pesticides than other types of agriculture. The paucity of such land use in the Mitch Hill Spring recharge area is beneficial to the protection of water quality in the spring.

Much of the Mitch Hill Spring recharge area is forested; the balance is primarily in grasses which are used for or hay. Sediment production during and following the clearing of woodlands and conversion to pasture grasses is obviously of concern since it can adversely impact water quality. However, in general, the conversion of woodland to pasture is unlikely to seriously impact water quality in the Ozarks. Unfortunately, there may be an exception to this general rule in the Mitch Hill Spring recharge area. The reason is that pasture lands in this region may follow a trend in northern Arkansas and begin to be utilized as disposal sites for liquid or solid animal wastes from poultry and hog confinement houses. The greater the amount of pasture land in the area, the greater the amount of animal wastes which may ultimately be land applied in the Mitch Hill Spring recharge area.

The animal wastes have substantial value as fertilizer, but the wastes also have the potential for creating serious groundwater contamination and pollution. Land application of animal wastes receives limited regulation from the Arkansas Department of Pollution Control and Ecology. The basic approach is to determine the amount of nutrients which the soils might be likely to retain. However, even at very low application rates and under ideal conditions, soils in karst areas never retain all of the nutrients which are applied to them; some of the nutrients will always enter the groundwater system.

Typically, land application of animal wastes in Arkansas focuses little attention on the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD) of the waste. Fresh liquid animal wastes as applied in northern Arkansas can have large BOD and COD values. If these wastes rapidly enter the groundwater system, they can seriously deplete the oxygen in the receiving water. Such oxygen depletion can lead to serious kills of aquatic life.

MANAGEMENT RECOMMENDATIONS FOR PROTECTING THE WATER QUALITY OF MITCH HILL SPRING

1. Water quality protection at Mitch Hill Spring requires that significant amounts of pollutants not be allowed to enter the groundwater system within the delineated recharge area for the spring. This area encompasses 20.8 square miles.

2. The areas which have the greatest potential for introducing pollutants into the Mitch Hill Spring groundwater system are those with Extremely High Hazard or High Hazard; these areas are depicted on the hazard area map which accompanies this report. Water quality protection efforts must be focused on these areas.

3. Protection of water quality in Mitch Hill Spring will require understanding and cooperation from the residents of the area. There has been extensive cooperation on water quality issues between residents of the area and the National Park Service in the past. We recommend that the National Park Service maintain contacts with CALF, a local citizen group at Pindall which is particularly concerned with protecting groundwater quality.

4. A broad public understanding of the location of recharge areas for important springs is a crucial first step in providing enhanced awareness and protection of these supplies. We recommend that the National Park Service make the results of our Mitch Hill Spring investigations available to relevant individuals and groups. Additionally, we recommend that the National Park Service make use of the findings of this study in interpretive programs at the Buffalo National River.

5. The proposed Bob Cash landfill represents the greatest single threat to the water quality of Mitch Hill Spring. The National Park Service should continue their efforts to prevent the establishment of this facility.

6. Highway spills must be recognized as the second most significant threat to the water quality of Mitch Hill Spring. Leaks and spills of hazardous cargoes within the Mitch Hill Spring recharge area need to be cleaned up rather than allowed to enter the groundwater system.

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